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Edition 1.0 2020-11

TECHNICAL SPECIFICATION

Rotating electrical machines –
Part 34: AC adjustable speed rolling mill motors

colour inside

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ROTATING ELECTRICAL MACHINES –

Part 34: AC adjustable speed rolling mill motors

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 60034-34, which is a Technical Specification, has been prepared by IEC technical committee 2: Rotating machinery.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
2/1995/DTS	2/2017/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60034 series, published under the general title *Rotating electrical machines*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Rolling mill DC motors have 100 years of successful history. These metal rolling mill motors have been manufactured based on specific U.S.A. National Electric Manufacturers Association (NEMA) standards.

However, the control technology development, owing to progress in semiconductor device technology and micro-processor application technology, has made it practical to use AC adjustable speed rolling mill motors, both induction and synchronous motor types.

On the other hand, structures and characteristics of AC motors are far different from those for DC motors. Therefore, for application of AC adjustable speed rolling mill motors the purchaser and equipment supplier need a common understanding. This document incorporates various technical aspects of experience with DC mill motors and AC motor application experiences.

It introduces the field weakening control concept and overload operation as applied to AC adjustable speed rolling mill motors, and uses this information to specify factory test voltages to be used.

Various types of overload capacity conditions and overloads are defined. The possible effect on motor insulation life due to operating the motor beyond its design capability is discussed.

Requirements for confirmation of motor under specified variable speed operational conditions are introduced.

Rolling loads are defined for several application conditions. These supplement the duty classifications in IEC 60034-1 with specific cases.

ROTATING ELECTRICAL MACHINES –

Part 34: AC adjustable speed rolling mill motors

1 Scope

This part of IEC 60034 is applicable to AC adjustable speed rolling mill motors and identifies specific requirements for AC adjustable speed rolling mill motors, where those performance characteristics are different from those for conventional AC motors.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034-1:2017, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-2 (all parts), *Rotating electrical machines*

IEC 60034-7:1992, *Rotating electrical machines – Part 7: Classification of types of constructions and mounting arrangements (IM Code)*
IEC 60034-7:1992/AMD1:2000

IEC 60417, *Graphical symbols for use on equipment – 12-month subscription to regularly updated online database comprising all graphical symbols published in IEC 60417*

IEC 61800-4:2002, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for a.c. power drive systems above 1 000 V a.c. and not exceeding 35 kV*

3 Terms and definitions

For purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
AC adjustable speed rolling mill motor
motor which is applied to metal rolling mill applications

Note 1 to entry: AC motors for rolling mills have the following specific features:

a) high short time overload capability;

b) strong mechanical construction to withstand shock load torque and vibration.

3.1.2
acceleration and deceleration torque
motor output torque available to accelerate or decelerate the driven load to a different speed

3.1.3
base frequency
frequency at rated output of the AC adjustable speed motor

Note 1 to entry: The motor base frequency is the transition point from the constant torque region to the reduced torque region when field weakening control is used.

Note 2 to entry: Base frequency is measured in hertz (Hz).

3.1.4
base speed
specified motor rotational speed at which the motor is capable of continuously delivering rated torque and rated output

Note 1 to entry: Base speed is the transition point between constant torque and field weakening operation.

[SOURCE: IEC 61800-4:2002, 3.4.4, modified – introduction of rated output condition.]

3.1.5
continuous overload capability
capability for long time overload operation where thermal equilibrium is reached

3.1.6
coupled
condition where the motor is attached to the driven equipment by means of a mechanical device or coupling

3.1.7
cut-off output
mechanical protection level based on motor output which, when exceeded, results in an immediate trip of the motor

3.1.8
cut-off torque
mechanical protection level based on motor torque which, when exceeded, results in an immediate trip of the motor

3.1.9
endshield bearing type motor
motor which has bearings mounted to the motor frame

3.1.10
field weakening range
speed range from base to top where motor flux is reduced from the value for rated torque

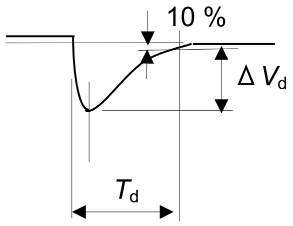
Note 1 to entry: IEC 61800-4:2002, 3.4.5 uses a similar term: "field weakening operation".

3.1.11
frequently applied overload output
output greater than rated which is frequently applied as part of normal rolling operation

3.1.12
frequently applied overload torque
torque greater than rated which is frequently applied as part of normal rolling operation

Note 1 to entry: This is a limit torque for normal rolling process which may be frequently applied provided the RMS value for load current does not exceed 1,0 p.u.

3.1.13
impact speed drop
phenomenon where rolling speed drops transiently due to a sudden load change due to material impact on the mechanical equipment (see Figure 1)



$$\omega_{impact\_drop} = \frac{\Delta V_d \times T_d}{2} (\%s)$$

Where

ω_{impact_drop} is the impact speed drop;

ΔV_d is the maximum speed drop (%);

T_d is the period of speed drop (s).

3.1.14
journal
part of the shaft where the load surface is in contact with the bearing sleeve

[SOURCE: IEC 60050-411:1996, 411-43-06, modified – relation with bearing sleeve is added.]

3.1.15
maximum safe operating speed
maximum motor rotational speed which does not lead to mechanical deformation nor deterioration in continuous operation

Note 1 to entry: The definition of maximum safe operating speed is modified from that in IEC TS 60034-25:2014, 18.6

3.1.16
overspeed
motor rotational speed which exceeds motor maximum safe speed

[SOURCE: IEC 60034-1:2017, 9.7, modified: changed to noun phrase and meaning of the speed is added.]

3.1.17
pedestal bearing type motor
motor which has separate bearing pedestal stands

3.1.18
radial load for bearing
mechanical load applied to the bearings in a radial direction

3.1.19
rated current
motor current when delivering rated output power

3.1.20
rated <motor> frequency
specified frequency corresponding to rated output of the motor

Note 1 to entry: Rated frequency is expressed in hertz (Hz).

3.1.21
rated output
output in mechanical power which is available at the shaft

Note 1 to entry: Rated output is expressed in watts (W) or kilowatts (kW).

Note 2 to entry: It is the practice in some countries for the mechanical power available at the shafts of motors to be expressed in horsepower (1 h.p. is equivalent to 745,7 W; 1 ch (cheval or metric horsepower) is equivalent to 736 W).

[SOURCE: IEC 60034-1:2017, 3.3, modified – “mechanical” and “available at the shaft”, have been added.]

3.1.22
rated power factor
motor power factor when delivering rated output

rated speed
specified rotational speed of the motor used to define the rated output power

Note 1 to entry: The definition of rated speed in 3.49 of IEC 61800-2:2015 does not consider rated output power in the field weakening range. The definition in IEC 61800-2 corresponds to term 3.1.4 of this document.

3.1.23
rated torque
motor torque at rated output and rated rotational speed

[SOURCE: IEC 60050-411:1996, 411-48-05, modified – definition simplified, considering the definition of 3.1.21: “rated output”.]

3.1.24
rating
set of rated values and operating conditions

[SOURCE: IEC 60034-1:2017, 3.2]

3.1.25
reversing operation
operation where normal motor rotation and opposite to normal motor rotation are repeated alternatively during load cycle

3.1.26
rolling torque
load torque
motor output torque for metal rolling or other connected load requirements

3.1.27
shock load
mechanical impact load applied from an external source

3.1.28
short time overload capability
capability for short time overload operation where thermal equilibrium is not reached

3.1.29
sleeve bearing
bearing where the load surface supporting the journal is cylindrical

[SOURCE: IEC 60050-411:1996, 411-42-07, modified – structure and shape are described.]

3.1.30
stall operation
operation generating torque while the motor is not rotating

Note 1 to entry: Special care should be taken to avoid overheating the converter power semiconductor devices and slip rings of a synchronous motor.

3.1.31
terminal voltage
line-to-line voltage at the motor terminals

3.1.32
thrust load
mechanical load applied to the bearings in an axial direction

3.1.33
top frequency
maximum design operational frequency of the AC adjustable speed rolling mill motor

Note 1 to entry: Top frequency is expressed in hertz (Hz).

3.1.34
top speed
specified highest motor rotational speed at which continuously rated output is available

3.1.35
torsional vibration
vibration caused by transient torque in the multi-mass spring system consisting of the motor, shafts, couplings, gears and driven equipment

3.2 Terms and definitions for adjustable speed control and rolling operation

3.2.1
automatic field weakening control
method which controls flux current inversely with speed to maintain the induction voltage constant from motor base speed to top speed

3.2.2
complete drive module
CDM
drive module consisting of, but not limited to, the basic drive module, which includes the electric power converter and related control, and extensions such as protection devices, transformers and auxiliaries, but excluding the motor and sensors which are mechanically coupled to the motor shaft

Note 1 to entry: Basic drive module (BDM) is defined in 3.4 for and Figure 2 of IEC 61800-2:2015.

[SOURCE: IEC 61800-2:2015, 3.8, modified – “the electric power converter and related control” is added]

3.2.3
current control
control of motor current

3.2.4
flux component current
component of current which is in quadrature with the motor's inductive voltage

3.2.5
overload current
motor current that exceeds motor design value

3.2.6
speed control
control of motor rotation speed

[SOURCE: IEC 61800-4:2002, Annex B]

3.2.7
torque control
control of motor torque

3.2.8
torque <component> current
component of current which is the same phase as the motor's inductive voltage and produces motor torque

3.2.9
unity power factor control
method which controls converter input power factor to 1,0

3.2.10
vector control
method which independently controls motor flux and torque producing currents

3.3 Terms and definitions for adjustable speed drive system

3.3.1
AC power drive system
power drive system for adjustable speed AC motor, which is defined in IEC 61800-2 for equipment below 1 000 V (low voltage) and IEC 61800-4 for equipment above 1 000 V (high voltage)

Note 1 to entry: PDS can include all equipment and control including the transformer, converter, motor and auxiliary systems.

[SOURCE: IEC 61800-2:2015, Clause 1, IEC 61800-4:2002, Clause 1.]

3.3.2
converter
unit which changes the form of main electrical power to the form supplied to the motor(s) by changing one or more of the voltage, current, and/or frequency

Note 1 to entry: The converter comprises electronic commutating devices and their associated commutation circuits. It is controlled by transistors or thyristors or any other power switching semiconductor devices.

Note 2 to entry: The converter can be line-commutated or self-commutated and can consist, for example, of one or more rectifiers.

[SOURCE: IEC 61800-2:2015, 3.9, modified – Reference to Figure 1 has been deleted.]

3.3.3
functional earthing
FE
grounding of electrical power system and equipment not for personal safety

Note 1 to entry: The definition of functional earthing is modified from that in IEC 60050-195:1998, 195-1-13.

3.3.4
harmonics
multiples of converter input power frequency included in converter output voltage and current

3.3.5
protective earthing
PE
grounding of electrical power system and equipment for personal safety

Note 1 to entry: The definition of protective earthing is modified from that in IEC 60050-195:1998, 195-1-11.

3.3.6
pulse width modulation control
PWM control
converter control method creating constant voltage pulse trains of various widths simulating variable frequency AC voltages

[SOURCE: IEC 60050-551:1998, 551-16-30, modified – definition is limited to the case simulating sinusoidal waveform.]

3.3.7
rated inverter voltage
output fundamental wave RMS voltage which defines inverter rated capacity

3.4 Terms and definitions for monitoring and protection sequence

3.4.1
overcurrent protection
protection against motor current exceeding design limits

3.4.2
overspeed protection
protection against motor speed exceeding design limits

3.4.3
overvoltage protection
protection against motor voltage exceeding design limits

3.5 Terms and definitions for motor installation and site trial operation

3.5.1
base
common supporting structure for all motor components

Note 1 to entry: Motor components include the stator and bearings.

3.5.2
shaft centring
installation adjustment to fit the motor shaft to the motor rotation shaft centre

3.5.3
sole plate
steel plate for the purpose of ensuring a level motor installation

3.5.4
trial operation
initial motor no-load operation uncoupled and coupled to the driven equipment

3.6 Terms and definitions for test

3.6.1
factory test
test conducted at the manufacturer's location

3.6.2
full load
load which causes a machine to operate at its rating, and which may be called "rated load"

[SOURCE: IEC 60034-1:2017, 3.6]

3.6.3
insulation resistance test
measurement to judge motor insulation condition using an insulation resistance tester

Note 1 to entry: An insulation resistance tester is usually used for measurement of insulation resistance. It is necessary to select applying voltage which is suitable for rated voltage and condition of the machine. 250 V or 500 V for low voltage circuit and 1 000V for high voltage circuit are used for the insulation resistance test.

[SOURCE: IEC 60034-27-4:2018, IEV 411-53-48]

3.6.4
no-load <operation>
state of a machine rotating with zero output power (but under otherwise normal operating conditions)

[SOURCE: IEC 60034-1:2017, 3.5]

3.6.5
no-load saturation curve <of synchronous motors>
performance curves of field current versus induced voltage when the synchronous motor operates as a generator at rated speed with the armature winding open-circuited

3.6.6
no-load test
test to determine machine characteristics under no load conditions

[SOURCE: IEC 60050-411:1996, 411-53-57, modified: simplified by referring to no load conditions and purpose of the test is added.]

3.6.7
site operation test
test conducted at the purchaser's location

3.6.8
thermal equivalent time constant
time constant, replacing several individual time constants, which determines approximately the temperature course in a winding after a step-wise current change

[SOURCE: IEC 60034-1:2017, 3.26]

3.6.9
visual inspection
inspection with the naked eye to determine if the motor is matched with the specification or if there is damage or a defect

3.6.10
withstand voltage test
test to confirm, by applying a stipulated voltage, that the strength of the insulation between energized parts and earth or between energized parts conforms to manufacturer's standards

Note 1 to entry: The definition of withstand voltage test is modified from that in IEC 60034-1:2017, 9.2.

4 Terminal voltage determination

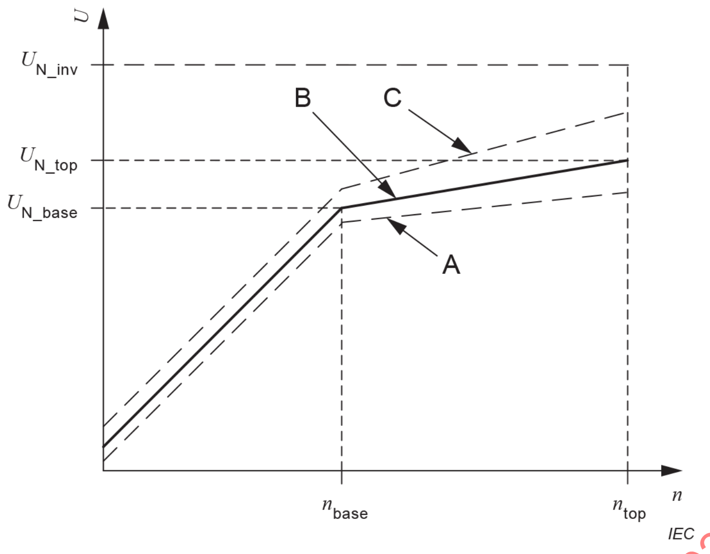
For constant speed AC motors, terminal voltage is determined by the connected power supply system voltage. For adjustable speed AC motors, terminal voltage is determined by converter output voltage. However, in order to determine the rated terminal voltage, the specific AC motor operational characteristics need to be taken into account. Specifically, the relationship between "flux" and "current" is required.

Examples of the specific AC motor operational characteristics are shown in Figure 1 and Figure 2. In the field weakening range, which corresponds to operation above base speed, the main flux is adjusted to be inversely proportional to speed in order to keep the motor's electromotive force (EMF) constant. In the field weakening range, the motor terminal voltage is gradually increased with increasing speed, in order to compensate voltage drop with increased current and frequency. Adjusting the main flux in this way ensures that the motor operates to produce constant output power from base speed to top speed.

Comparing Figure 1 and Figure 2 demonstrates that the voltage increase for induction motors above base speed is greater, however the terminal voltage can be kept constant in synchronous motors. Furthermore, the terminal voltage for AC adjustable speed rolling mill motors could be further increased due to the overload torques identified in Annex A and Annex B.

For AC adjustable speed rolling mill motors:

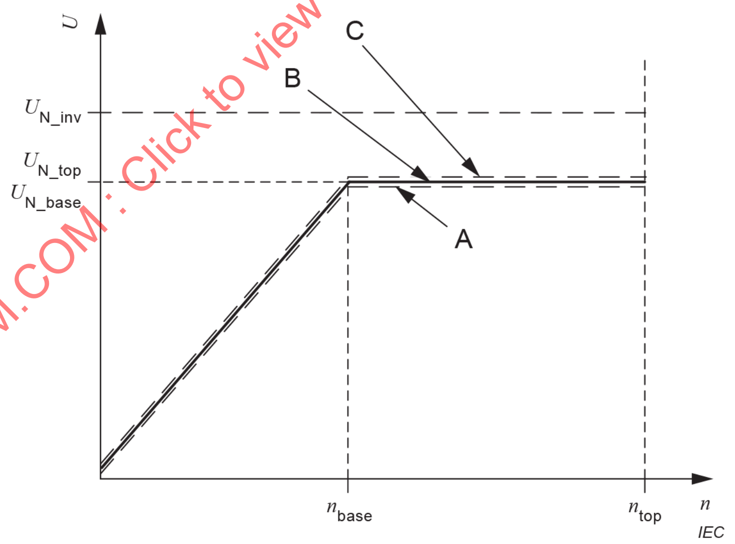
- Withstand voltage E is determined by the maximum effective AC output voltage of the semiconductor converter.
- The voltage required at the maximum overload condition determines the maximum terminal voltage required by both induction and synchronous motors, typically in the field weakening range.
- For induction motors the base speed terminal voltage is lower than the terminal voltage at top speed in the field weakening range.



Key

A no load
B rated load
C overload
U_{N_base} motor terminal voltage at base speed and rated load
U_{N_top} motor terminal voltage at top speed and rated load
U_{N_inv} rated inverter voltage
n_{base} base speed
n_{top} top speed

Figure 1 – Example of induction motor terminal voltage versus speed



Key

A no load
B rated load
C overload
U_{N_base} motor terminal voltage at base speed and rated load
U_{N_top} motor terminal voltage at top speed and rated load
U_{N_inv} rated inverter voltage
n_{base} base speed
n_{top} top speed

Figure 2 – Example of synchronous motor terminal voltage versus speed

NOTE Motor torque versus speed requirements, including overload requirements, determine motor physical body size. Induction motors designed based on Figure 1 will be physically smaller than one designed without terminal voltage increase as shown in Figure 2.

5 Duty type and temperature class

5.1 General

In Clause 5 the selection of duty type S9 and S1 for specific applications is reviewed. In the case of DC metal rolling mill motors, duty type S9 was the dominate case. More recently new applications have evolved which may be regarded as duty type S1.

The concept of winding temperature deviation, $\Delta\theta$, in one rolling cycle is provided as a guide in the selection of Class B or Class F temperature rise when the motor has Class F insulation. Refer to 5.5 and Annex C.

In the event the motor is operated in a manner that causes the motor temperature to exceed the temperature class, motor life will be decreased according to the following discussion.

In the case where 115 % continuous operation is defined as a requirement, the motor shall be designed for 115 % of its rated power continuously, without exceeding the temperature rise limit of the insulation class, according to the design criteria in IEC 60034-1. For continuous overload capability, refer to Clause 6.

One method to achieve normal motor life is to design the motor to operate one temperature rise down from the applied insulation system class; for example, a Class F insulation system designed to operate with a Class B temperature rise for the specified operational condition. Refer to 5.5.

The 125 % for 2 h is a legacy DC rating and shall not be applied to AC motors. In this case the rolling mill actual duty cycle shall be determined and the motor sized accordingly.

NOTE For DC rolling mill stand motors, insulation Class F with Class B rise was specified in NEMA MG-1 [6][1], such as Hot Strip Mill (abbreviation “HSM” is used hereinafter) rougher and plate mill main motors. It was sometimes also applied to Art-2 motors such as HSM finishing and TCM stand motors.

5.2 Selection of rolling operation pattern

The first step in determining winding temperature deviation in one rolling cycle is identifying the rolling operation pattern based on Annex B. Specific parameters for estimating the winding temperature deviation in one rolling cycle include:

- torque current and rotational speed when the material enters the roll bite;
- time in seconds after the material enters the roll bite and before the mill accelerates to a higher speed;
- torque current and rotational speed at operational speed;
- time in seconds for accelerating the mill to operational speed;
- time in seconds in the field weakening range.

The selected rolling operation pattern is used to calculate the estimated winding temperature deviation.

[1] Numbers in square brackets refer to the Bibliography.

5.3 Evaluation of winding temperature deviation during one rolling cycle

Short-time high overload capability is a feature of rolling mill motors for duty type S9. The precise overload capability versus rotational speed is discussed in Annex A. However, the winding temperature rise deviation is not specified.

The overload torque and overload output power capabilities require increased winding currents, which impact the transient winding temperature rise. If the overload currents are maintained for a time close to the winding temperature rise time constant (the thermal equivalent time constant), then significant transient temperature changes may occur which causes a significant temperature deviation in one rolling cycle.

The allowable super-temperature, which is temperature difference between the maximum temperature and the average temperature value in one rolling cycle, is 25 K under the 100 % rated RMS load unless otherwise specified. The winding temperature deviation in one rolling cycle shall be estimated in accordance with Annex C using either the simplified method (Clause C.2) or the precise method (Clause C.3).

5.4 Duty type S1 or S9 selection

The duty type is determined by the mechanical equipment supplier for new installations. When upgrading from DC to AC systems, consideration should be given to the application as the operational cycle may have changed with time.

The concept of "negligible thermal impact" is introduced for the case where the winding temperature deviation in one rolling cycle $\Delta\theta$ is less than 1 K. If the winding temperature deviation in one rolling cycle at rated load is estimated to be of negligible thermal impact, S1 can be applied. In all other cases S9 shall be applied.

NOTE The relative thermal life shortening for the 1 K super-temperature case is less than 10 % and used as the "1 K" for S1/S9 selection criteria, as is explained in Table 1.

In this estimation, the relative thermal life index expression is:

$$TL = 1/\left(2^{\Delta\theta/k}\right)$$

where

$\Delta\theta$ is the super-temperature in one rolling cycle at rated load;

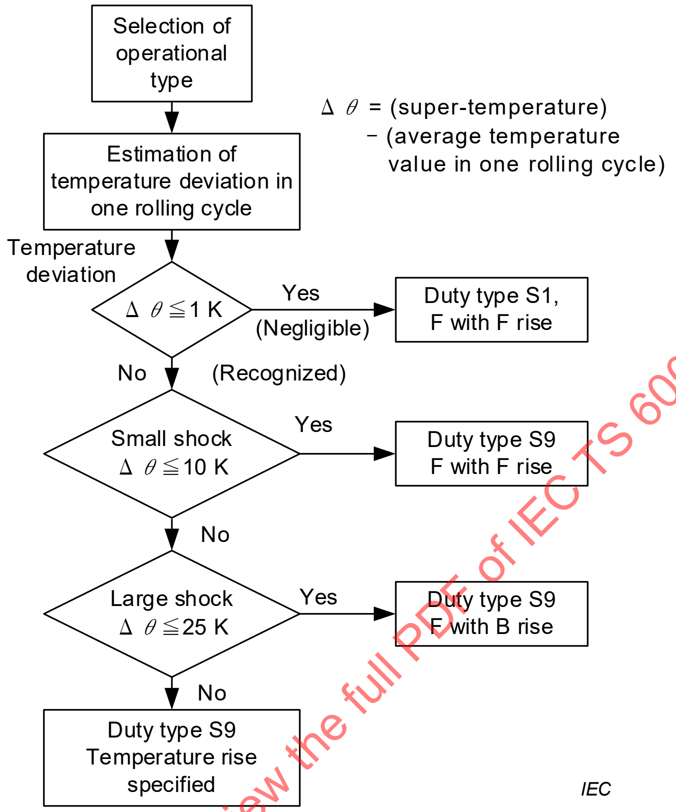
k is the temperature rise in kelvins, which leads to a shortening of the thermal life expectancy of the insulation system by 50 %. Here, the k value is assumed to be 10 K.

Table 1 – Thermal life shortening due to the super-temperature in one rolling cycle

The super-temperature in one rolling cycle K	Relative insulation aging speed p.u. $2^{\Delta\theta/k}$	Relative thermal life expectancy *TL* p.u. $1/2^{\Delta\theta/k}$	*TL* %	Thermal life shortening %
10	2,000	0,500	50,0	50,0
5	1,414	0,707	70,7	29,3
2,5	1,189	0,841	84,1	15,9
2	1,149	0,871	87,1	12,9
1	1,072	0,933	93,3	6,7

5.5 Class B rise or Class F rise selection

The assignment of the duty type S9 does not automatically imply that Class F insulation with Class B rise is required. The flowchart in Figure 3 also considers winding temperature deviation in one rolling cycle and the shock load conditions applied to the motor as the selection criteria.



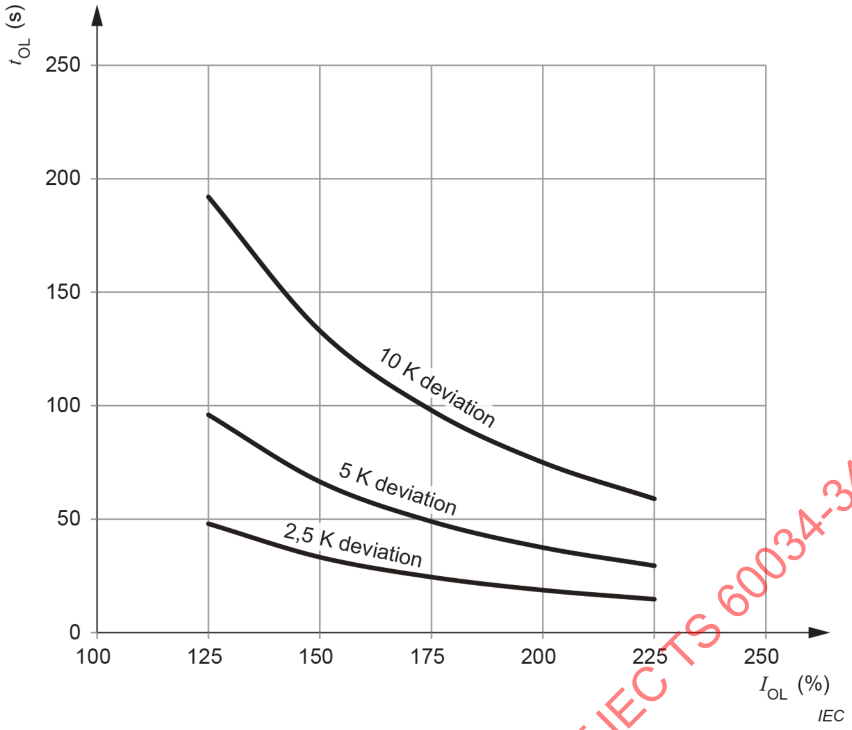
NOTE Temperature rise can be the same, but mechanical design should be different in case of Class F insulation with Class F rise.

Figure 3 – Selection of motor temperature rise based on the temperature deviation in one rolling cycle and shock load conditions

5.6 Overload current duration time limit based on winding temperature deviation in one rolling cycle for RMS current of 100 %

Overload current duration time limits based on Annex D, are plotted in Figure 4 for winding temperature deviations of 10 K, 5 K and 2,5 K. The winding temperature deviation is calculated between the maximum and mean values in one rolling cycle with the condition that the RMS current over the operational duty cycle is 100 %.

The operational cycle used is that of a hot strip mill finishing stand.



Key

t_{OL}	overload current duration limit in seconds for 2,5 K, 5 K, and 10 K deviation
I_{OL}	square waveform approximated overload current as a percentage
2,5 K deviation	allowable winding temperature deviation of 2,5 K in one rolling cycle
5 K deviation	allowable winding temperature deviation of 5 K in one rolling cycle
10 K deviation	allowable winding temperature deviation of 10 K in one rolling cycle

Figure 4 – Example of overload current duration time limit based on winding temperature deviation between maximum and mean, in one rolling cycle RMS current of 100 %

NOTE Figure 4 is based on a thermal equivalent time constant of 20 min.

6 Continuous overload capability

6.1 General

Continuous overload capability is required in emergency or unusual situations and therefore is infrequently required. In the case where continuous overload capability operation is applied, temperature can be beyond the specified temperature rise defined in IEC 60034-1. For example, in the case that insulation 155 (F) with temperature 130 (B) rise is specified, winding temperature rise can be allowed up to the class 155 (F) rise under 115 % continuous operation.

Duty type S10 is used only to determine motor insulation life reduction. The relative thermal life index (TL) value may be estimated by the motor manufacturer upon request. Such exceptional cases include:

a) in case of special material which is rarely rolled – continuous overload operation with an RMS value of motor load greater than 100 %;

b) in case of hot strip mills or tandem cold mills where motor failure is considered in advance – the continuous overload operation is evaluated for the remaining operational motors based on the repair time for the failed motor.

The continuous overload capability shall not be applied without any specific requirements.

The continuous overload capability shall not be applied to reserve margins for thermal stress in winding insulation due to winding temperature deviation in one rolling operation cycle, and to reserve margins for mechanical stress in winding insulation due to the mechanical rolling shock and due to the frequent accelerations and decelerations.

In these cases, thermal margins are reserved by the application of duty type S9 mill motors where the thermal class for the winding temperature rise is one rank down compared with the thermal class for the insulation system, as is described in 5.4.

The following three types are specified for the continuous overload capability.

- Type 1:

  When the continuous overload output is required in the actual service operation and the duration hours as a percentage of annual service operation hours are considered to be negligible or less than 0,5 %, based on agreement between the supplier and purchaser. In this case the relative thermal life index (TL) value can be estimated as TL = 1,0.

  For this case, the following shall be included in the motor documentation:

  Overload 115 % continuous, Δt: < 0,5 %, TL value: 1,0.

- Type 2:

  When the continuous overload duration hours as a percentage of annual service operation hours is estimated as 10 %, the TL value is estimated as:

  TL: 0,60 for 115 % overload.

  according to the simplified TL value estimation method in 6.2.

  For this case, the following shall be included in the motor documentation:

  Overload 115 % continuous, Δt: 10 %, TL value: 0,60 for 115 % overload.

  A TL value of 0,6 means that the expected thermal insulation life of this motor, operating at the nominated duty, is 60 % of the expected life of the same motor operating without any continuous overload exposure. Likewise, a TL value of 0,25 means that the expected thermal insulation life of this motor, operating at the nominated duty, is 25 % of the expected life of the same motor operating without any continuous overload exposure.

- Type 3:

  When the continuous overload output duration hours as a percentage of annual service operation hours is estimated as more than 0,5 % and other than 10 %, the purchaser shall determine the Δt value as a percentage of annual service operation hours. The supplier shall evaluate the TL value according to the TL value calculation methods of either the simplified method in 6.2 or the precise method in 6.3.

In any type of continuous overload output application, the motor shall accommodate the overload output mechanically without a decrease in life expectancy. The use of the motor under the above conditions requires that the converter is capable of matching the continuous overload output requirements.

IEC 60034-1 defines the duty type S10 which allows for multiple overload output periods. However, in 6.2 it is recommended that the load variation be simplified to only two stages of discrete constant loads: 100 % constant load and one more than 100 % constant load. This allows the TL value to be calculated using the simplified method.

6.2 Relative thermal life index of TL value estimation by simplified method

The precise method specified in 6.3 is accurate but is considered to be too complicated to apply in actual practice. In addition, the required parameter values may not be available at mill motor rating planning stage. Therefore, the simplified method is introduced using the 10 K halves insulation life law.

For example, in the case of 115 % overload duty with Δt:10 % and 100 % continuous load with Δt:90 %, let the winding temperature rise at 100 % continuous load be 100 K. The winding temperature rise at 115 %-continuous is then 132 K (100 K × $(1,15)^2$).

Rounding 132 K down to 130 K for simplification, 130 K is greater than 100 K by 30 K. It results in eight times ($2^3 = 8$) reduction in insulation life using the 10 K halves insulation life law where 30/10 = 3.

Let Δt for 115 %-continuous be 10 %, and Δt for 100 % load be 90 %. Then

Deterioration for 115 % operation: 8 × Δt = 8 × 0,1 = 0,8

Deterioration for 100 % operation: 1 × Δt = 1 × 0,9 = 0,9

for a total of 0,8 + 0,9 = 1,7.

Therefore, the TL value = 1/1,7 = 0,59, or a relative thermal life of 59 % compared to continuous duty type S1 for a machine designed to operate at 100 K temperature rise.

6.3 Relative thermal life estimation by precise method

If the continuous overload capability relative thermal life value TL is to be determined by the precise method, the following procedure is to be followed in advance of the TL value calculation.

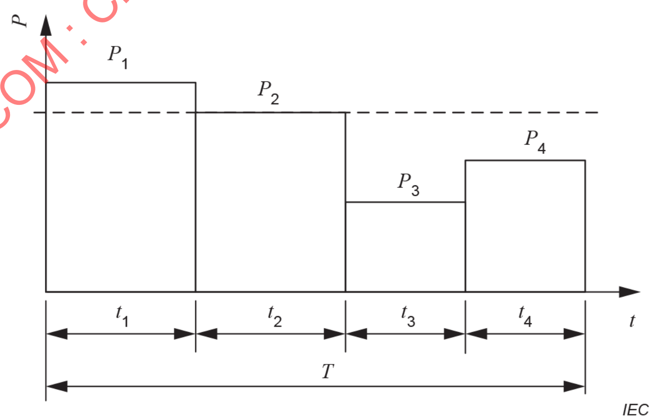
a) Define the load repetition cycle (in hours or in days) for which the continuous overload output operation is required.

b) At least four steps of discrete constant loads shall be assigned within the load repetition cycle, where for at least one step of the discrete constant loads one overload output operation shall be assigned.

c) For the load repetition cycle, load values of P_1, P_2, P_3, P_4, and their duration time of t_1, t_2, t_3, t_4, shall be assumed.

d) According to Annex D, calculate the relative thermal life index of TL value.

Figure 5 is an example of discrete constant loads with 115 % continuous overload.



Key

P	load	t	time in long hours
P_1	115 % overload	t_1	115 % continuous overload period
P_2	rated load	t_2	rated load period
P_3	50 % load	t_3	50 % load period
P_4	75 % load	t_4	75 % load period
T	long hour load cycle		

Figure 5 – Example of discrete constant loads with 115 % continuous overload

If the estimated relative thermal life index of *TL* value is less than the expected value, the motor rating shall be increased or the temperature rise limit shall be decreased to meet the expected value.

6.4 Relative thermal life index of *TL* value determination by precise method

Refer to IEC 60034-1.

7 Mechanical requirements

7.1 General

Rolling mill motors shall satisfy the mechanical requirements established by the rolling mill designer. The supplier and purchaser in consultation with the designer shall discuss and agree upon the requirements.

7.2 Mechanical strength for shaft and other transmission parts considering torsional vibration

Allowable torque applied to the motor shaft shall be twice that of the frequently applied maximum torque. Larger torques may be requested and agreed upon between the supplier and purchaser.

NOTE In this document, mechanical fatigue life strength for the motor shaft of almost 400 % to 500 % of rated torque is specified.

Around the 1970s, United States and Japan experienced main shaft break accidents and the other torque transmission parts break accidents in blooming mills and plate mills. Therefore, the iron and steel associations of US and Japan, together with motor manufacturers, investigated both field measurements and torsional analysis [1].

As a result of the investigation, the conclusion of "allowable torque applied to the motor shaft shall be twice that of the frequently applied maximum torque" was introduced firstly to the JEM 1157 Standard: 2002, [2] of Japan Electric Manufacturers Association of JEMA, secondly to JEC 2140 Standard: 2016, of I.E.E. of Japan [3].

7.3 Vibration transmitted through the motor base

Allowable vibration acceleration values transmitted through the motor foundation shall be less than 9,8 m/s^2. Larger allowable vibration values may be requested and agreed upon between the supplier and purchaser.

7.4 Tangential forces applied to rotor and stator

The speed and torque time chart shall be specified by the purchaser for the motor manufacturer to determine the tangential load. The stator shall also be able to withstand the tangential load transmitted by electromagnetic force from the rotor to the stator.

7.5 Thrust load

7.5.1 General

Unless specified, the thrust load applied to the motor from the connected load shall be smaller than that of the motor itself. The thrust load shall be specified by the purchaser in accordance with 7.5.2 to 7.5.4.

7.5.2 Frequently applied thrust load

The frequently applied thrust load is a thrust load which is frequently applied in normal service operation. The continuously applied thrust load shall be also defined as the frequently applied thrust load.

7.5.3 Occasionally applied maximum thrust load

The occasionally applied maximum thrust load is a thrust load which is occasionally applied in normal service operation for a short duration. The lubrication oil film for bearings needs to be maintained during this time.

7.5.4 Emergency maximum thrust load

The emergency maximum thrust load is a thrust load which is applied when the motor shall be stopped immediately, such as in the case of a broken roll or spindle shaft.

7.6 Radial load for bearings

The radial load for bearings from the driven equipment shall not be normally applied to the motor. However, one second coupling weight load shall be taken into account for motor design.

In cases where the motor shaft is directly connected to the load without the benefit of an outside support bearing, the radial load for bearings shall be assigned based upon agreement between the supplier and purchaser.

7.7 Overspeed

Refer to IEC 60034-1.

An overspeed test is optional. If the test is required, the test duration shall be 2 min.

NOTE For very low speed motors, overspeed caused by sudden load change at tail off is more than 1,2 times of the maximum speed. Agreement for special overspeed may be made between the purchaser and the supplier.

7.8 Stator coil end fixation

In view of the vibration from the foundation due to overload torques and shock loading, the coil end of the stator coil shall be firmly fixed. The structure of series and/or parallel connection of the coils shall be able to withstand repetitive shocks.

7.9 Stator shift construction for maintenance inspection

Stator shift structure is the structure which enables shifting the stator in the axial direction for rotor maintenance. If this structure is requested by the purchaser, the supplier will ensure its delivery.

7.10 Mounting code application

Generally, this motor shall follow the mounting code specified in IEC 60034-7. However, for special cases, the requirements in Annex G are recommended in addition to the existing IEC 60034-7:1992 requirements, if applicable.

8 Withstand voltage capability

8.1 Rotor bars or damper bars and short-circuit rings

According to the operation pattern of rolling mill drives specified in Annex C, rotor bar currents alternate between no load and heavy load. For damper bars in synchronous motors, high currents take effect due to the impact of material roll bite. As a result, not only mechanical shocks but also thermal expansion and contraction are impacting on the rotor bars.

Rotor bars for induction motors and damper bars for synchronous motors along with the slip ring circuit shall be able to withstand repetitive mechanical shocks and mechanical stress due to the heat cycle.

8.2 General

Clause 4 and Clause 5 discuss the terminal voltage increases due to the differences between induction and synchronous motors under steady state and short-time overload operations. These changes cannot be ignored for AC adjustable speed rolling mill motor design and testing. Therefore, the withstand voltage capability and withstand voltage test voltage shall be applied for the worst-case conditions which correspond to top speed, minimum field and frequently applied overload torque or overload output power conditions.

Motor insulation electrical stresses shall be in accordance with Clause 7 of IEC TS 60034-25:2014.

8.3 Withstand voltage test

The test shall be done in accordance with IEC 60034-1. The motor voltage shall be considered to be the maximum effective AC converter output voltage. The test results shall be included in the factory test record.

8.4 Withstand voltage capability

8.4.1 General

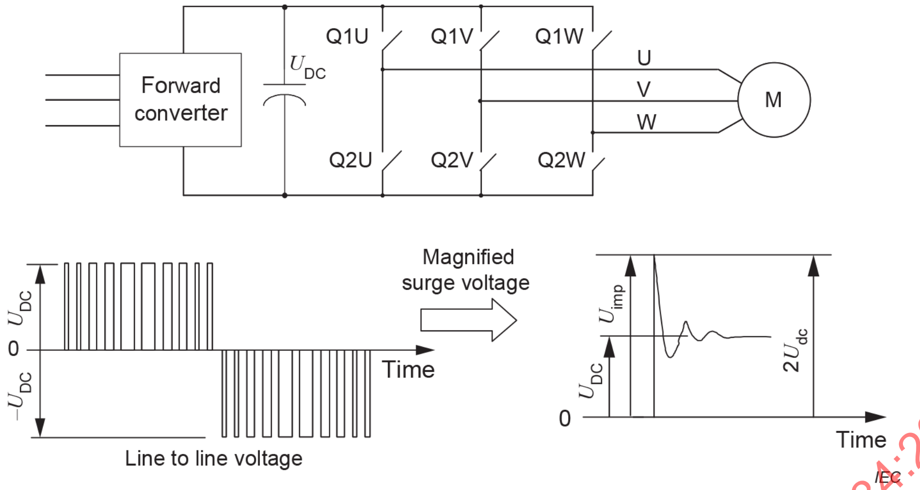
The insulation system design of power converter driven motors shall consider the following items specified in 8.4.2 and 8.4.3.

8.4.2 Ground insulation

Additional DC surge voltages will be applied to the motor by the converter output voltage as shown in Figure 6 and Figure 7. Therefore, insulation design for converter driven motors shall consider the additional voltages.

The output of pulse width modulated (PWM) converters, applying PWM control; contains higher-order harmonics that may affect motor insulation life. It is recommended that the motor manufacturer obtain the expected harmonic spectrum from the converter manufacturer.

In addition, leakage current through ground insulation will be increased due to the fast rise time of the PWM converter output voltage (dv/dt). Therefore, the insulation design for the motor shall also consider this factor.



Key

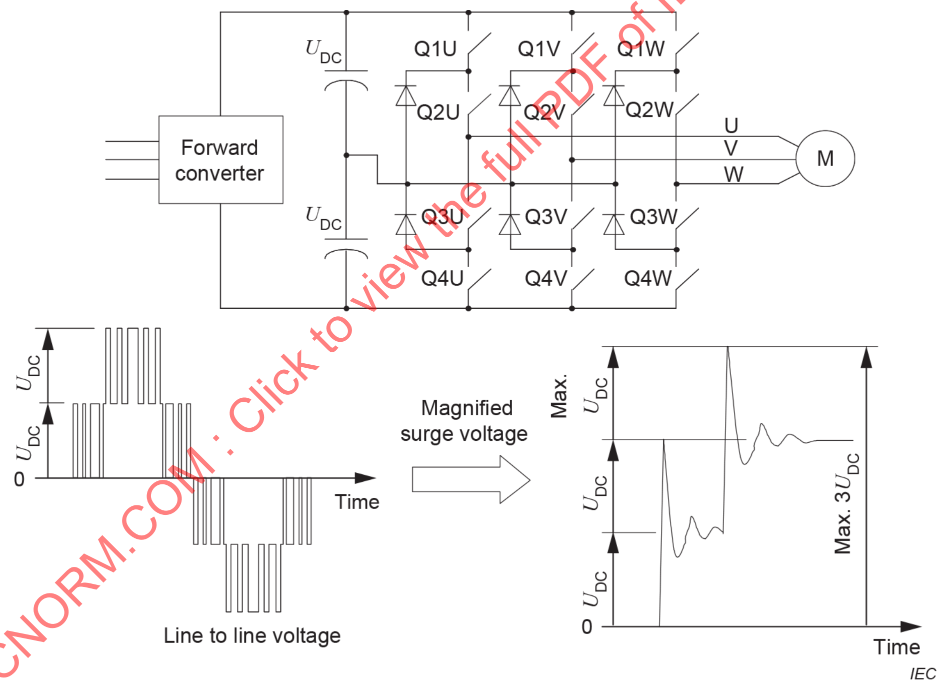
U_{DC} line to line DC voltage

U_{imp} impulse voltage

Q1U, V, W semiconductor power switching device

Q2U, V, W semiconductor power switching device

Figure 6 – 2-level inverter configuration, waveform and switching surge voltage



Key

U_{DC} line to line DC voltage

Q1U, V, W semiconductor power switching device

Q2U, V, W semiconductor power switching device

Q3U, V, W semiconductor power switching device

Q4U, V, W semiconductor power switching device

Figure 7 – 3-level inverter configuration, waveform and switching surge voltage

8.4.3 Turn-to-turn insulation

PWM converter driven motors are subjected to a much higher dv/dt than that of a sinusoidal voltage. Therefore, a far higher turn-to-turn voltage is applied to the motor. For these motors not only ground insulation, but also turn-to-turn insulation considering dv/dt is required.

9 Factory tests and recommended site operation tests

9.1 General

9.1.1 General scope for the tests

For motors following this document, ratings and performances should be verified by both factory test and site operation tests according to IEC 60034-2. Additionally, to account for specific effects of the specific complete drive module (CDM) several site operation tests are recommended.

For the factory test, ratings and inherent performance of induction motors or synchronous motors shall be verified. The motor is not driven by the specific CDM, but is driven by a conventional factory test power source.

For the site operation test, no-load speed characteristics especially in the field weakening range should be verified in accordance with 9.5 and the torque-speed characteristic, specified in Annex A, should be estimated based on the acceleration and deceleration tests, specified in 9.6. The motor should be driven by the specific CDM.

NOTE The site operation test specified in Clause 9 can be applied in the motor factory if the specific CDM can be installed and operated in the motor factory.

9.1.2 Requirements of the site operation test where vector control is applied

NOTE The term vector control refers to both field-oriented control and direct torque control [4].

The AC adjustable speed rolling mill main motors are driven by phasor vector control, in which the main flux vector and the torque component current vector are independently controlled in the rotational quadrature axis, as is explained in Annex E and in Annex F.

In vector control the angle between the main flux vector and the torque component current vector is kept at a right angle of 90°. Far different operational characteristics from those of conventional AC motors driven at fixed voltage and frequency can be achieved.

The operation characteristics where orthogonal constraint control between flux vector and torque current vector is applied are specified in Clause 4 and in Annex A. In terms of torque-speed characteristics, some deviations between the test results and the specified values are to be assumed. In a properly tuned CDM, these deviations are caused by inaccuracy of the orthogonal constraint control due to motor characteristic deviations.

Therefore, it should be confirmed that the deviations are within the allowable limits, in both no-load and on-load tests.

a) No-load test

   For the motor and its drive system coupled test, speed reference is to be given first to the speed control regulator. Then the torque current reference is to be given as a result of speed control function to the current control regulator. Finally, the terminal voltage reference is given as a result of current control regulators.

   The terminal voltage reference is never given first but is based on the results of the speed/current control functions. Therefore, the results of the site no-load test will necessarily have deviations from the assumed values. With a properly tuned CDM the deviations result from motor characteristic deviations.

The terminal voltage deviations from the terminal voltage characteristics versus rotational speed, as specified in Figure 1 and Figure 2, should be precisely checked versus the motor withstand voltage capabilities.

b) On-load test

For the AC adjustable speed rolling mill main motors, acceleration and deceleration load/torque tests are to be applied instead of the real load.

In this case, the ramp speed reference, where the speed acceleration rate of dn/dt is constant, is given to the control system. The torque current, field current for the synchronous motors, and the terminal voltage references are derived in the control system.

Therefore, some deviations on the torque component current, field current for synchronous motor and terminal voltage are to be expected due to motor characteristic deviations. It should be confirmed if those deviations are within allowable limits.

The acceleration and deceleration test results also allow for the estimation of the overload torque capability or overload output power capability versus speed as specified in Annex A.

9.2 Factory test

In this document, rating related test items and induction machine/synchronous machine inherent performance related test items shall be verified by the motor manufacturer's factory test, in accordance with the existing standards in the IEC 60034 series.

For the factory test, the rating related test items and induction machine/synchronous machine inherent performance related test items shall be verified not only for the base speed but also for the top speed, where $U_{\mathrm{N\_base}}$ of “motor terminal voltage at base speed and rated load” specified in Clause 4 and base frequency shall be applied for the base speed with the rated power factor condition and where $U_{\mathrm{N\_top}}$ of “motor terminal voltage at top speed and rated load” specified in Clause 4 and top frequency shall be applied for the top speed with the rated power factor condition.

For ratings related test items, temperature rise by the temperature rise test shall satisfy the criteria specified in Clause 8 of IEC 60034-1:2017. The measured motor losses shall assure the mechanical output power ratings are within the specified input conditions, in accordance with the existing IEC 60034-2 series, in which the "losses determination" is specified in terms of "effciency determination".

For performance related test items for induction motors, the secondary resistance of R_2, for example, is examined by the locked rotor test at several frequencies at the motor manufacturer’s factory test.

The R_2 value can be useful as an initial control system setup.

For performance related test items for synchronous motors, the synchronous reactance X values, for example, are examined by both the no-load saturation characteristic results and the three-phase short circuited current characteristic results.

The X values can be useful as an initial control system setup.

The above tests shall be applied to both base speed and top speed.

9.3 Preparation before trial operation at site

9.3.1 General

In 9.3.2 to 9.3.9, a number of checks are recommended to facilitate commissioning. Neither the sequence nor the number of checks is mandatory.

9.3.2 Calibration of feedback signals for the converter

All feedback signals required by the converter for motor control should be verified and calibrated to the extent possible. These include items such as speed sensors, speed limit switches and resistance temperature detectors.

9.3.3 Insulation resistance tests for motor

Insulation resistance tests should be made for the assembled motor with the motor uncoupled from the driven equipment. Evaluation of the test results should include comparison with those from the factory test, considering the site temperature and humidity conditions compared to the factory conditions.

9.3.4 Insulation resistance tests for bearings

Insulation resistance tests for bearings should be made for the assembled motor. The test results should be compared against the factory standard. The tests and any rectification work should be performed until the factory standard is met.

9.3.5 Performance test for bearing lubrication oil supply unit

Forced or flood lubrication oil system for motor bearings tests are to be done after the piping installation work has been completed, including flushing of the pipes, the lubrication oil has been filled and the oil pump unit has been installed. The performance test includes:

- confirmation of no oil leakage anywhere around the piping;
- confirmation of no abnormal sounds or abnormal vibration at the pump unit;
- confirmation of smooth and sufficient flow of the lubrication oil by visual inspection at the oil sight gauge near the bearing housing.

9.3.6 Confirmation of lubrication oil surface level for bearings

For motors with forced lubrication oil systems, confirmation of the lubrication oil surface level for sleeve bearings should be made with the motor at zero speed and with the pump unit operating.

For motors with self-lubrication oil systems, confirmation should be made with the motor running at the slowest expected operating speed. This is a visual inspection of all bearings at the oil site gauge on the bearing housing.

9.3.7 Performance test for cooling systems

After checking that the cooling air ducts and cooling water piping (if any) are properly assembled and installed, the performance test for cooling systems is done. These include the following checks:

- confirmation of no cooling air flow leakage and/or confirmation of no cooling water leakage;
- confirmation of no abnormal sounds or abnormal vibration at the cooling equipment, including cooling fans, cooling fan drive motors and cooling water pumps (if any);
- confirmation of proper input electric power to the cooling equipment.

9.3.8 Confirmation of alarm issue levels for motor protection

For direct torque drive in phasor vector control, the terminal voltage, the torque component current and the motor speed are determined as a result of the direct torque drive. Therefore, it should be confirmed that the alarm levels of the overvoltage protection, the overcurrent protection and the overspeed protection, are set to the proper values.

When alarms are installed with specific protective devices, such as stator temperature detectors, bearing temperature detectors, it should be confirmed that the alarm levels are set to the proper value.

9.3.9 Synchronous motor pole position confirmation test

This test is a real time determination of rotor pole position for adjustable speed synchronous motors. The rotating pole position is the relative position between the rotor pole and the equivalent three-phase stator windings. The purpose of the test is to determine pole position and rotational direction for use by the converter control.

In principle, pole position is estimated by the zero-crossing point of electromotive force induced by magnetic flux distribution. However, this method requires generator operation where the subject motor is driven by another motor. For the site trial operation where another driving motor is not available, the method is based on the pole position at which motor torque becomes zero causing no rotational movement by adding positive and negative DC current pulses to each phase winding as described in Annex F.

9.4 Site uncoupled trial operation

9.4.1 General

The following procedures in 9.4.2 and 9.4.3, are recommended to be undertaken to confirm proper operation of the drive system.

9.4.2 Rotational speed build-up test

For this test the motor should be started with very low speed, typically 2 % of top speed. Then the motor speed should be increased step by step, starting with 10 % of the top speed, where the following inspections should be applied at each speed step, including the very low speed:

- confirmation of no abnormal sound around the motor;
- confirmation of no abnormal vibration anywhere on the motor, including the motor bearings;
- confirmation of no abnormal axial movement (end play) of the motor shaft;
- confirmation of no abnormal temperature in association with the bearings and windings;
- confirmation of no abnormal inlet and outlet cooling air temperature for motors so equipped;
- confirmation of normal lubrication oil flow by visual inspection at the oil sight gauges;
- confirmation by the converter speed feedback signal that the speed sensor is properly aligned. Continue until the speed feedback signal has been properly aligned for the converter requirements.

For reversing mill motors, where the reversing operations are applied during rolling, the inspections described above should be applied for forward and reverse rotation.

9.4.3 Bearing temperature rise test

After the motor has completed the rotational speed build-up test, the bearing temperature rise test should be done. Healthy lubrication oil flow during the test should be confirmed and the bearing temperature rise test continued until the temperature has stabilized.

9.5 Site no-load characteristic test

9.5.1 Induction motor no-load characteristics test

In advance of this test, the factory no-load flux current values for the complete speed range should be loaded into the converter control. Then motor terminal voltages should be measured for each step of speed reference values at the converter.

The test of terminal voltage at base speed includes the following.

- The speed reference signal value is for base speed.
- Flux current I_{1d}, calculated from the excitation current value from the factory test record, is applied as a starting value.

If the measured terminal voltage differs from the rated value, adjustment of flux current I_{1d} should be made such that the measured terminal value equals the rated value. Then the terminal voltages and supply frequencies should be confirmed for several steps of speed reference values between zero speed and base speed.

The test of terminal voltage between base speed and top speed is done after the zero to base speed tests. The terminal voltages and supply frequencies should be measured for several steps of speed reference values between base speed and top speed.

A slow acceleration from base speed to top speed and back to base speed should confirm that the terminal voltage can maintain the design value. This test confirms both proper motor assembly and the motor design.

9.5.2 Synchronous motor no-load characteristics test

In advance of this test, the factory no-load field current values for the complete speed range should be loaded into the converter control. Then motor terminal voltages should be measured for each step of speed reference values at the converter.

The test of terminal voltage at base speed includes the following.

- The speed reference signal value is for base speed.
- Field current I_{f0_base} from the no-load saturation curve for the rated terminal voltage from the base speed factory test record is applied as a starting value.

If the measured terminal voltage differs from the rated value, adjustment of field current I_{f0_base} should be such that the measured terminal value equals the rated value. Then the terminal voltages and supply frequencies should be confirmed for several steps of speed reference values between zero speed and base speed.

The test of terminal voltage between base speed and top speed is done after the zero to base speed tests. Adjustment of I_{f0} should be applied such that the terminal voltage may maintain the design value for several equally divided points of speed between base speed and top speed. The I_{f0} value for base speed is known as I_{f0_base} and I_{f0} for top speed is I_{f0_top}.

A slow acceleration from base speed to top speed and back to base speed should confirm that the terminal voltage can maintain the design value. This test confirms both proper motor assembly and the motor design.

9.5.3 No-load characteristics test record

It is recommended that the test results be recorded.

9.6 Site acceleration and deceleration test

A rapid acceleration, during which no part of the motor or converter control is saturated, from base speed to top speed and back to base speed should confirm that the terminal voltage can maintain the required value. This test confirms both the motor design and the converter control capability. The converter input speed reference is linearly ramped from zero speed to top speed, typically over a 10 s time period. Linear motor acceleration should be confirmed, where constant acceleration and deceleration torque are obtained.

It should be noted that these tests will typically be done uncoupled and repeated when the motor is coupled to the driven load. In any case, the acceleration time should be such that the maximum rotor peripheral acceleration does not exceed 9,8 m/s^2.

It is recommended that the test results be recorded.

10 Grounding

10.1 General

Modern power converter output waveforms are not perfect sinusoids but include various harmonic components of the fundamental frequency. These harmonics can introduce unwanted currents in magnetic structures. To avoid damage to motor bearings and instrumentation, as well as to protect personnel safety, it is important to properly earth the various components of the drive system. Basic and special grounding requirements are covered in Clause 10. Refer to Figure 8 for an overview of the major components.

10.2 Protection against bearing currents

Refer to IEC 61800-4 for medium voltage inverter for mechanical system integration requirements.

10.3 Protective earthing (PE)

The AC power drive system consists of an AC adjustable speed rolling mill motor, converter and transformer. Therefore, a grounding bus protective earthing is required between the motor and the other components.

The protective earthing conductor shall be indicated with the characters "PE", labelled with the symbol ⏚[IEC 60417-5019:2006], or clearly indicated in the instruction manual.

10.4 Functional earthing (FE)

There are various sensors, such as speed sensors, mounted on the motor. When sensor signals are transmitted to the converter control, the sensor shield cable should not be connected with the protective earthing. In this case, the shield cables are connected with the functional earthing. The shield should be grounded at the receiving terminals.

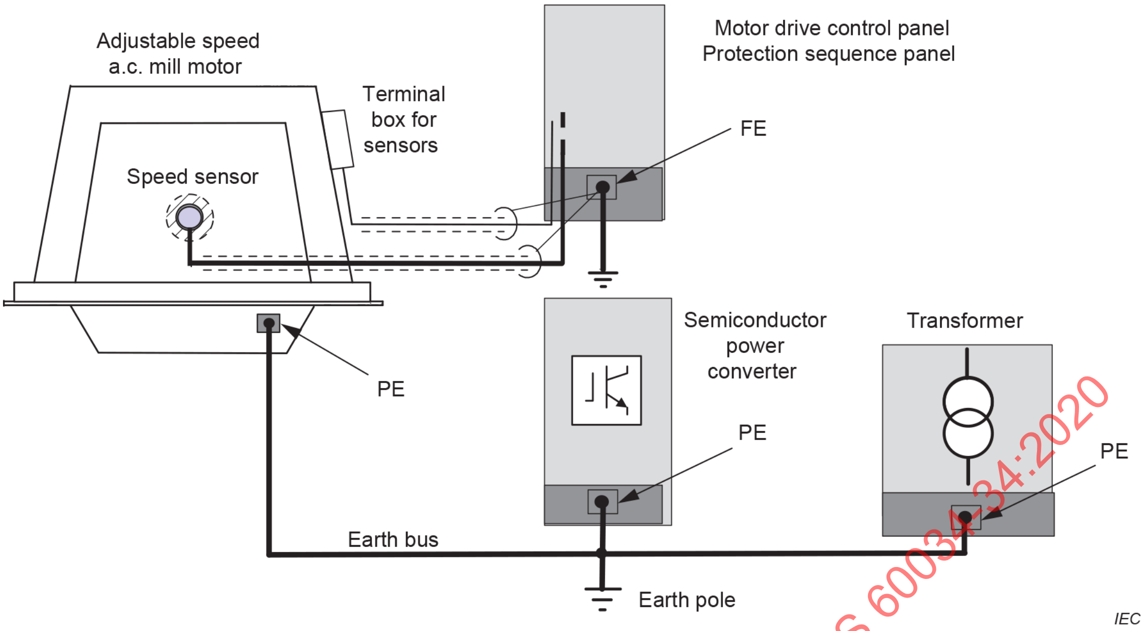


Figure 8 – Example of protective earthing and functional earthing

The protective earthing may be categorized and separated for high voltage, low voltage, control, etc., according to the suppliers' standards. Rules for grounding systems are not specified in this document but they shall comply with the local installation standards, including those for personnel protection.

11 Rating plate

The rating plate shall show the information stipulated in IEC 60034-1, plus the value of the overload torque capability, as a percentage, and the motor classification Art-1 or Art-2 as defined in Annex A and specified in Annex B for various applications.

For rolling mill motors not specified in Annex B, it is recommended that the overload torque capability value and the classification of Art-1 or Art-2 of the motor supplied be marked on the rating plate.

A second rating plate may also be supplied that includes the required information.

NOTE The additional marking requirements in this Clause 11 are based on the existing requirements in IEC 60034-3 [5].

Annex A
(normative)

Short-time overload capability

A.1 General

In Annex A, the AC adjustable speed rolling mill motors are classified as Art-1 or Art-2 motors, in accordance with their short-time overload capability requirements. The overload capabilities are defined as "frequently applied". The "short-time overload capability" is also known as "momentary overload capability".

The classification of Art-1 and Art-2 motors is referred to as motor classification in this document.

Art-1 motors are typically specified for hot reversing mill stand motors, where the reversing operation is applied during rolling, such as plate mills and hot strip mills (HSM) rougher applications where the momently applied overload torque is typically more than 200 %. This overload torque and overload output power are required for the large reduction of rolled material thickness in one pass.

Art-2 motors are typically specified for continuous rolling mill motors, such as HSM finishing mill and tandem cold mill (TCM) applications where overload output power may be required for acceleration, deceleration and impact loads from the rolling operation. Overload torque is basically not allowed, except for acceleration during rolling and except for transient torsional torque.

The short-time overload capability requirements shall determine the duty type as defined in Clause 5, considering both the winding temperature deviation in one rolling cycle and the shock load/vibration conditions applied to the motor. The capability shall be harmonized between the manufacturer and purchaser according to Annex B.

The overload capability values specified in Table A.1 and Table A.2 are default values unless otherwise specified. The values may be modified in accordance with the process requirements or historical experience as agreed upon by the purchaser and supplier.

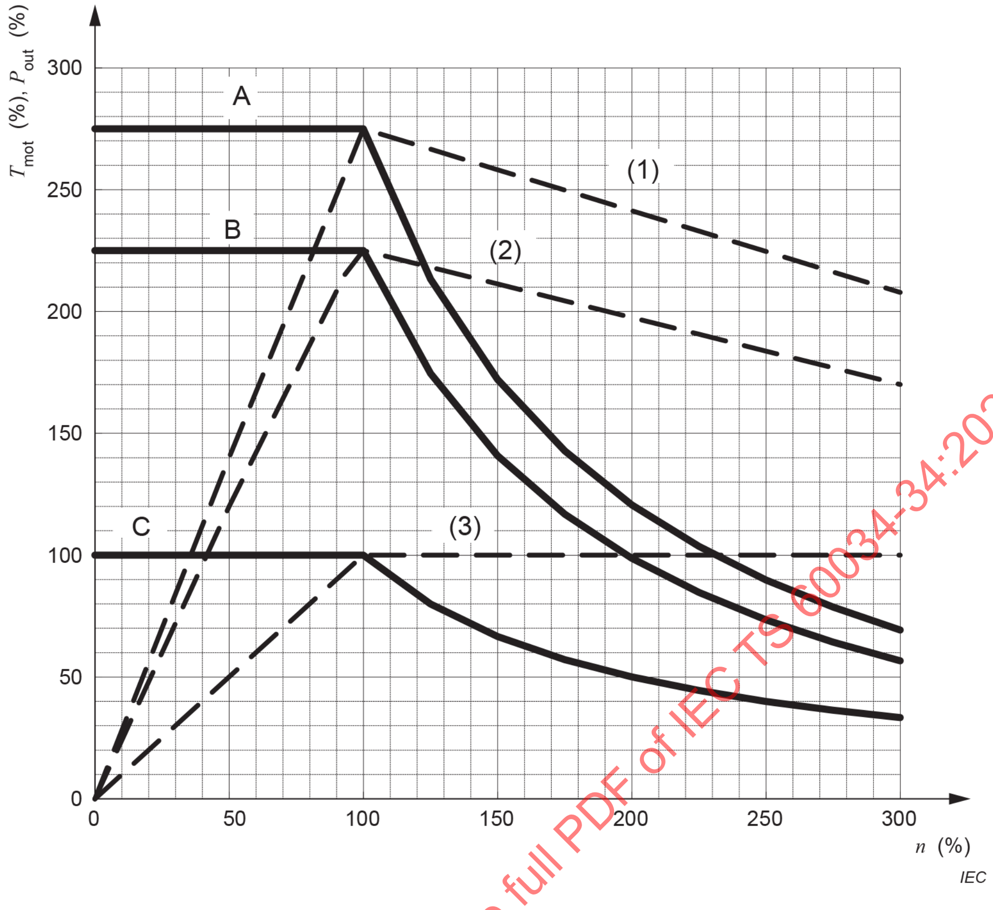
A.2 Frequently applied Art-1 short-time overload capability specification

The Art-1 motor is a motor which accelerates and decelerates rapidly, typically within 2 s or 3 s. In addition, it has very large short-time overload torque and overload output power, often with frequent motor rotation reversing, and rapid load variations. The Art-1 motor is classified as the following three types.

a) The Type-A motor maximum output torque is reduced above base speed according to the legacy DC NEMA MG.1.23 [6] as shown in Figure A.1.
b) The Type-B motor maximum output torque is not reduced above base speed as shown in Figure A.2.
c) The Type-S motor is a motor other than Type-A or Type-B.

The Art-1 motor is generally applied in reversing operations; however, it can also be applied to non-reversing operation with rapid load variations.

For Type-A motor and Type-B motor, the allowable overload output power duration interval shall be up to 60 s, unless otherwise specified.



Key

n rotational speed on the basis of base speed

T_{mot} torque applied to the motor

P_{out} output power of the motor

A cut-off torque

B frequently applied maximum torque

C rated torque

(1) cut-off output

(2) frequently applied maximum output

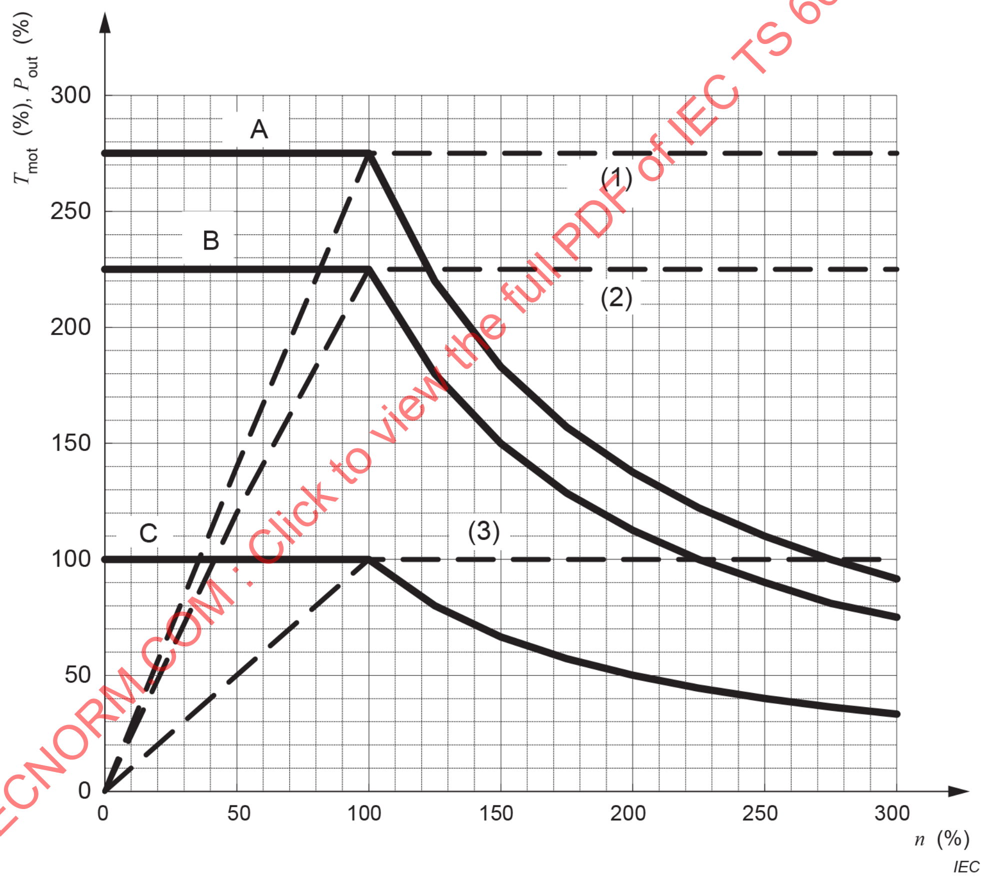
(3) rated output

Figure A.1 – Art-1 short-time overload capability of Type-A motors

Table A.1 – Art-1 short-time overload capability of Type-A motors

All values are expressed as percentages

Rotational speed on the basis of base speed	Cut-off torque	Cut-off output power	Frequently applied overload torque	Frequently applied overload output power	Torque for rated torque current	Output power for rated torque current
0	275	0	225	0	100	0
50	275	140	225	120	100	50
100	275	275	225	225	100	100
150	172,1	258	140,8	211	66,7	100
200	120,7	241	98,8	198	50	100
250	89,8	225	73,5	184	40	100
300	69,3	208	56,7	170	33,3	100



Key

n rotational speed on the basis of base speed

T_{mot} torque applied to the motor

P_{out} output power of the motor

A cut-off torque

B frequently applied maximum torque

C rated torque

(1) cut-off output

(2) frequently applied maximum output

(3) rated output

Figure A.2 – Art-1 short-time overload capability of Type-B motors

Table A.2 – Art-1 short-time overload capability of Type-B motors

All values are expressed as percentages

Rotational speed on the basis of base speed	Cut-off torque	Cut-off output power	Frequently applied overload torque	Frequently applied overload output power	Torque for rated torque current	Output power for rated torque current
0	275	0	225	0	100	0
50	275	140	225	120	100	50
100	275	275	225	225	100	100
150	183	275	150	225	66,6	100
200	137,5	275	112,5	225	50	100
250	110	275	90	225	40	100
300	91,6	275	75	225	33,3	100

A.3 Frequently applied Art-2 short-time overload capability specification

The Art-2 motor is a motor whose acceleration and deceleration times are generally much longer than the Art-1 motor. Typical acceleration and deceleration times are in the range of 10 s to 20 s. The short-time overload capability is also generally less and the motor reverses only infrequently.

The Art-2 motor is generally applied in a coordinated process involving several rolling stands whose relative speeds closely track during acceleration, steady state operation and deceleration, with strip or bar tension regulated between adjacent rolling stands. Therefore, only overload output power is specified instead of overload torque capability.

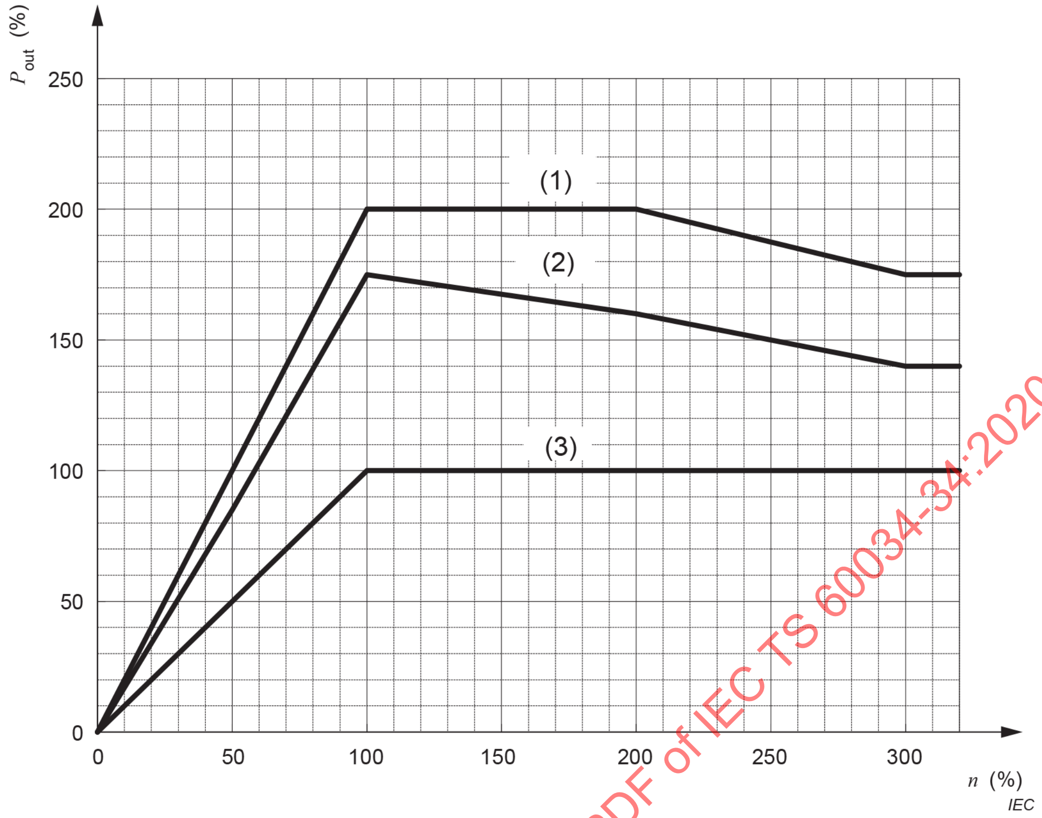
The Art-2 motor is classified as the following three types.

a) The Type-A motor maximum output power is reduced above base speed according to the legacy DC NEMA MG.1.23 as shown in Figure A.3 **and** Table A.3.

b) The Type-B motor maximum output power is maintained above base speed. The Figure A.4 and Table A.4 case is a default one for AC motors unless otherwise specified.

c) The Type-S motor is a special custom output reduction pattern for above base speed.

For Type-A motor and Type-B motor, the allowable overload output power duration interval shall be up to 60 s, unless otherwise specified.



Key

n rotational speed on the basis of base speed

P_{out} output power of the motor

(1) cut-off output

(2) frequently applied maximum output

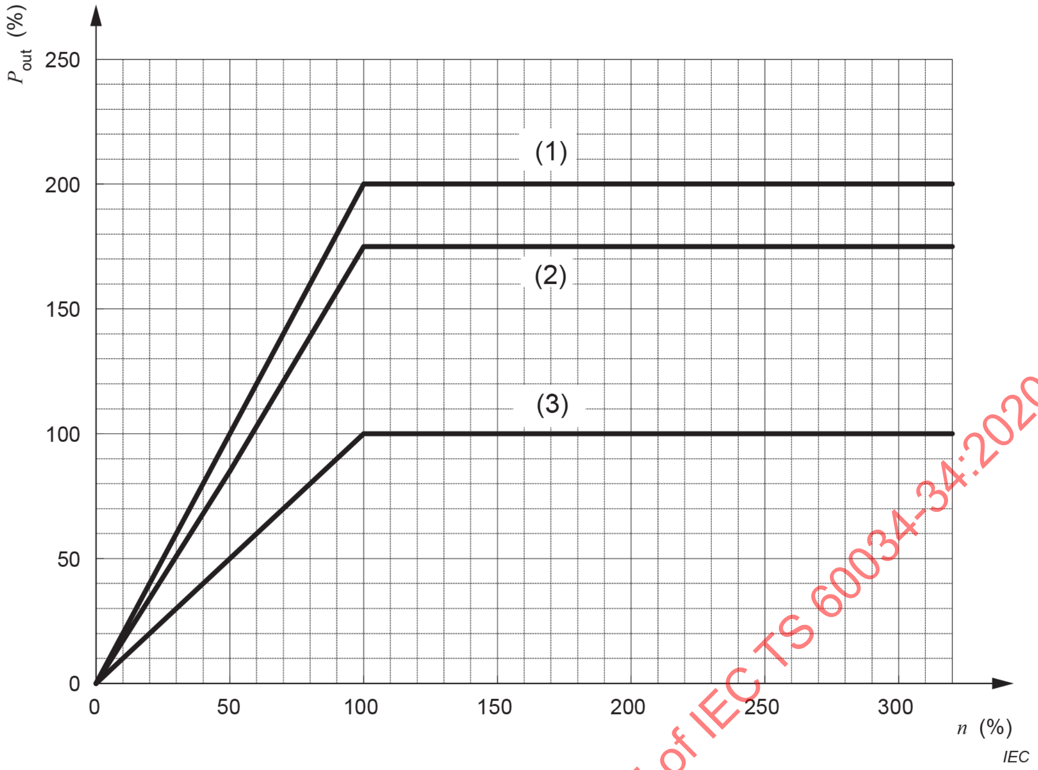
(3) rated output

Figure A.3 – Art-2 short-time overload capability of Type-A motors

Table A.3 – Art-2 short-time overload capability of Type-A motors

All values are expressed as percentages

Rotational speed on the basis of base speed	Cut-off output power	Frequently applied overload output power	Output power for rated torque current
0	0	0	0
50	100	85	50
100	200	175	100
150	200	167,5	100
200	200	160	100
250	187,5	150	100
300	175	140	100



Key

n rotational speed on the basis of base speed

P_{out} output power of the motor

(1) cut-off output

(2) frequently applied maximum output

(3) rated output

Figure A.4 – Art-2 short-time overload capability of Type-B motors

Table A.4 – Art-2 short-time overload capability of Type-B motors

All values are expressed as percentages

Rotational speed on the basis of base speed	Cut-off output power	Frequently applied overload output power	Output power for rated torque current
0	0	0	0
50	100	85	50
100	200	175	100
150	200	175	100
200	200	175	100
250	200	175	100
300	200	175	100

Annex B
(normative)

Rolling operation pattern designation

B.1 General

In Annex B, seven types of rolling operation patterns are defined based on actual application in representative rolling facilities. The purchaser shall designate one of these rolling operation patterns as applying for the supplier to determine the motor classification as defined in Annex A and the duty type as defined in Clause 5. Values for speed and load variations and time intervals shall be specified.

In cases where the continuous overload capability as defined in Clause 6 is specified, the rolling operation patterns in Annex B shall also be referenced.

NOTE Even though other rolling operation patterns can be assumed, they follow the format of the seven patterns in Annex B.

B.2 Rolling operation pattern for hot reversing rolling

The rolling operation pattern for hot reversing rolling is shown in Figure B.1,where the reversing operation is applied during rolling, typically involving a single stand although multiple stands may be involved. This rolling operation pattern may apply to plate mills, roughing stands of hot strip mills, structure mills and bar mills.

In this operation pattern:

a) Heavy loads, light loads and no-load rolling cycles are repeated in alternate motor rotational directions, within a time which is far shorter than the thermal equivalent time constant of the mill motors.
b) Rolling interval for one pass can be quite short but with high motor overload torques.
c) Both rolling speed and period are generally increased, as the number of rolling passes is increased, and applied "duty with non-periodic load and speed variations".
d) Overload torque operation at less than base speed is often scheduled.
e) Frequently applied Art-1 short-time overload capability, specified in Clause A.2, shall be specified so that the capability can withstand the overload torque from the mill stand.

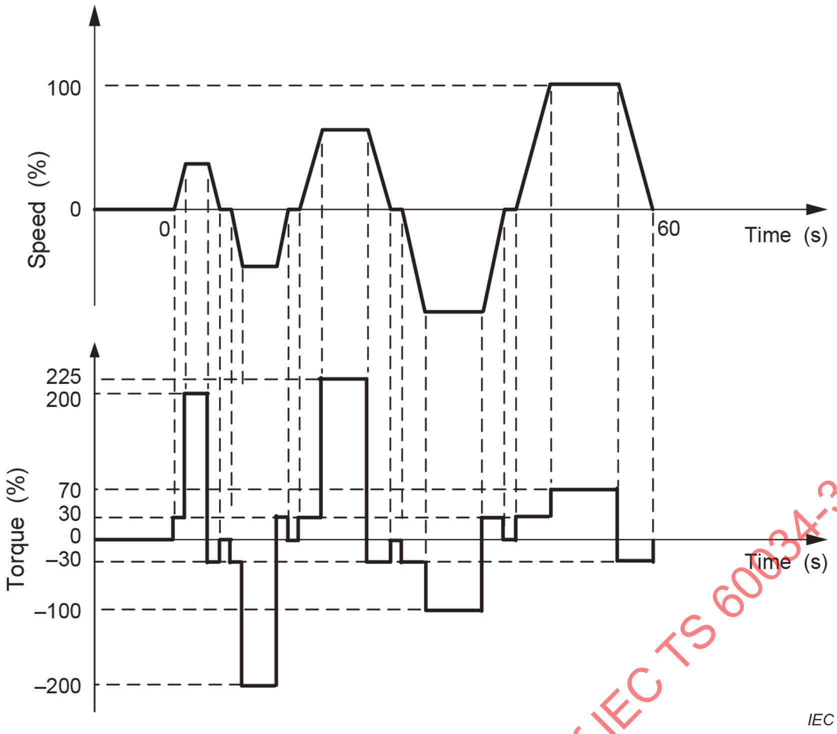


Figure B.1 – Typical rolling operation pattern for hot reversing rolling

B.3 Rolling operation pattern for hot continuous rolling of sheet strip

The rolling operation pattern for hot continuous rolling of sheet strip is the operation pattern, where hot sheet materials are rolled in a single pass, and where the mill motor rotation direction is only in one direction. The pattern is shown in Figure B.2.

In this operational pattern:

a) Light load condition without rolling and heavy load condition with rolling are repeated alternately.

b) Rolling speed is generally accelerated to the field weakening region during heavy load conditions.

c) Instantaneous heavy overload torque is required to minimize impact speed drop when the rolled material enters the mill stand.

d) Rolling interval for each rolled material is normally in between 60 s and 120 s, which is shorter than the thermal equivalent time constant of the mill motors. However, as the period of light load condition without rolling is normally short, this rolling operation pattern should be regarded as the continuous load from the view point of the thermal condition.

e) Frequently applied Art-2 short-time overload capability, specified in Clause A.3, shall be specified so that the capability can withstand the overload power from the mill stand.

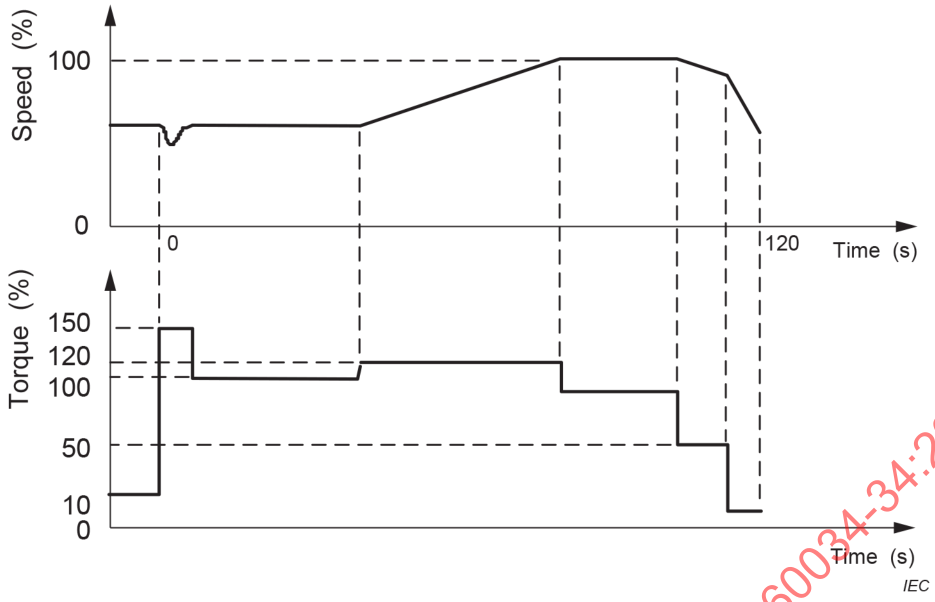


Figure B.2 – Typical rolling operation for hot continuous rolling of sheet strip

B.4 Rolling operation pattern for continuous caster directly connected hot continuous rolling mills

The rolling operation pattern for continuous caster directly connected hot continuous rolling mills is the operational pattern where the rolled materials are continuously rolled for a long time and without the light load condition occurring while waiting for the next material. In this case the mill motor rotation direction is only in one direction. The pattern is shown in Figure B.3.

In this operational pattern:

a) The period of heavy load condition is normally the same as the thermal equivalent time constant of the mill motors, because the rolled materials are welded for each other.

b) Motor load is constant within its rated condition as the rolling schedule cannot be changed and motor speed acceleration and deceleration basically does not exist, except for slight acceleration and deceleration to adjust rolling tension.

c) The rated torque for the mill motor shall be more than the rolling torque.

d) Frequently applied Art-2 short-time overload capability, specified in Clause A.3, shall be specified so that the capability can withstand the overload power from the mill stand.

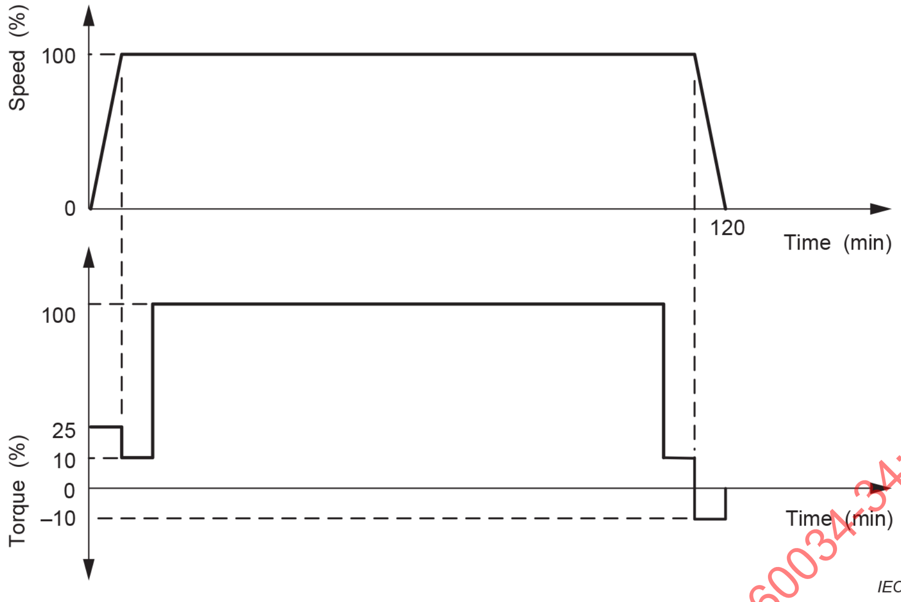


Figure B.3 – Typical rolling operation pattern for continuous caster connected hot continuous rolling for sheet strip

B.5 Rolling operation pattern for hot continuous rolling for wire and rod mills

The rolling operation pattern for hot rolling for wire and rod mills is an operational pattern where the rolled material is rolled in a single pass, and where the mill motor rotation direction is only in one direction. The pattern is shown in Figure B.4.

This rolling operation pattern is applied to rougher mills, intermediate mills and finishing mills of the wire and rod rolling mills.

In this operation pattern:

a) Light load condition without rolling and heavy load condition with rolling are generally repeated alternately.

b) Continuous operation at field weakening region is often applied during rolling.

c) Instantaneous overload torque is required to recover from impact speed drop due to material entering the roll bite.

d) Short-time overload output power for the finishing mills is relatively larger than that for rougher mills or intermediate mills.

e) The rolling interval is approximately between 90 s and 180 s, which is shorter than the thermal equivalent time constant of the mill motors. However, the light load operation time waiting for the next rolled material is normally short, therefore this rolling operation pattern should be regarded as the continuous load from the view point of thermal conditions.

f) Continuous overload torque or overload output power of around five minutes. Overload is caused by reduced temperature of rolling materials and shall be considered due to the rolling interval typically being fairly long.

Compared with hot continuous rolling of sheet strip:

1) The rolling interval for each material is longer.

2) Short-time overload torque at the material roll bite is generally smaller, and especially for rougher mills. Short-time overload torque is smaller than for wire and rod finishing and intermediate mills.

3) The acceleration and deceleration during rolling is not applied frequently.

4) Frequently applied Art-2 short-time overload capability, specified in Clause A.3, shall be specified so that the capability can withstand the overload power from the mill stand.

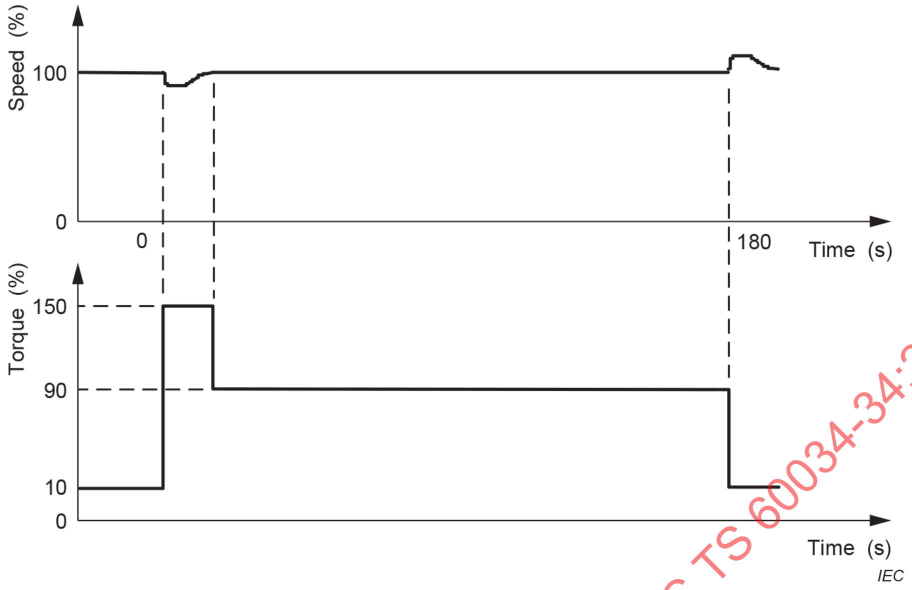


Figure B.4 – Typical rolling operation pattern for hot continuous rolling for wire and rod mills

B.6 Rolling operation pattern for cold reversing rolling mills

The rolling operation pattern for cold reversing rolling mills is the operational pattern where multiple passes with reversing operations are used. This pattern is shown in Figure B.5.

In this operation pattern:

a) The rolling interval for each pass is comparatively long, between 180 s and 600 s. However, the operation stop interval for reversing the mill motor rotation direction is normally short. Therefore, this rolling operation pattern should be regarded as continuous load from the view point of thermal condition.

b) The acceleration and deceleration during rolling is frequently applied, and this operation causes short-time overload output power conditions.

c) As the number of rolling passes is increased, the rolling load is decreased and the rolling speed and the rolling interval are increased.

d) Frequently applied Art-2 short-time overload capability, specified in Clause A.3, shall be specified so that the capability will withstand the overload power from the mill stand.

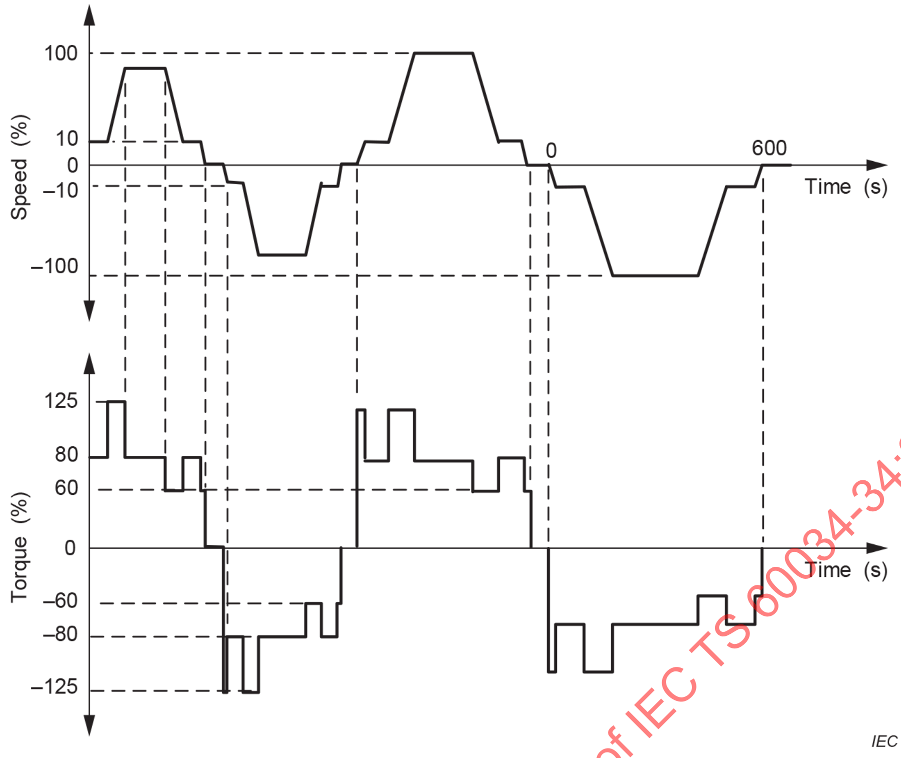


Figure B.5 – Typical rolling operation pattern for cold reversing rolling mills

B.7 Rolling operation pattern for cold continuous rolling

This operational pattern for cold continuous rolling is the operation pattern where cold sheet strip material is rolled continuously in a single pass through tandem rolling mills, and where the mill motor rotation direction is only in one direction. The pattern is shown in Figure B.6.

In this operation pattern:

a) Rolling load continues for a long time when the tail-end of rolled material is welded with the head of the next material.

b) Acceleration and deceleration during rolling material is frequently applied, causing short-time overload output power conditions.

c) Stall operation is an operation pattern, where the strip tension between the rolling stands is maintained and where the motor rotation speed is zero.

d) Frequently applied Art-2 short-time overload capability, specified in Clause A.3, shall be specified so that the capability can withstand the overload power from the mill stand.

NOTE In case of DC motors, the stall operation is severely restricted to avoid commutator profile distortion or brush seizure. On the other hand, in case of AC motors the restriction is generally less severe. However, slip ring profile distortion for synchronous motor, local heating in the motor windings and power converter semiconductor device limitations give restrictions.

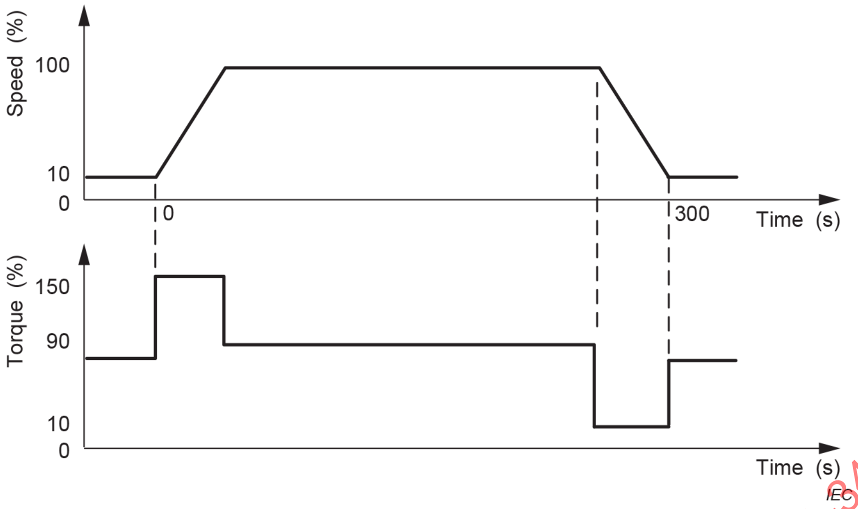


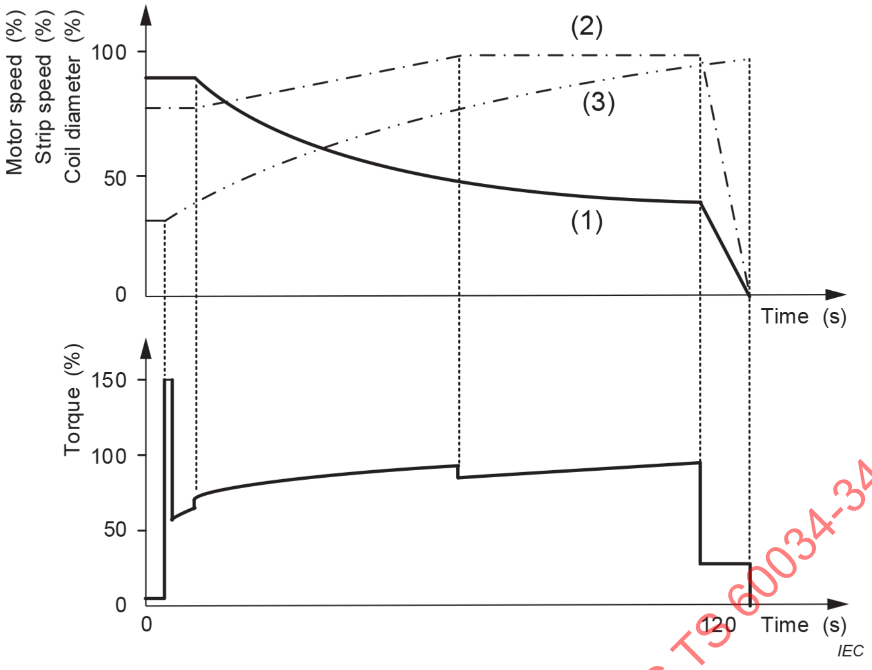
Figure B.6 – Typical rolling operation pattern for cold continuous rolling

B.8 Operation pattern for coilers and reels

This operation pattern for coilers and reels is an operational pattern where the sheet strip material is coiled. The term coiler refers to hot rolling mills and the term reels refers to cold rolling processes. The pattern is shown in Figure B.7.

In Figure B.7, the coiler is rotating at standby speed and after the sheet strip is wound once or twice the rotation speed of motor is accelerated such that the winding speed and mill speed are synchronized. The motor rotation is stopped after the coil winding is completed.

The motor typically has a wide field weakening range with constant power over the speed range. Frequently applied Art-2 short-time overload capability, specified in Clause A.3, shall be specified so that the capability can withstand the overload power from the coiler or reel.



Key

(1) motor speed

(2) strip speed

(3) coil diameter

Figure B.7 – Typical rolling operation pattern for coilers and reels

Annex C
(informative)

Determination of winding temperature deviation in one rolling cycle

C.1 General

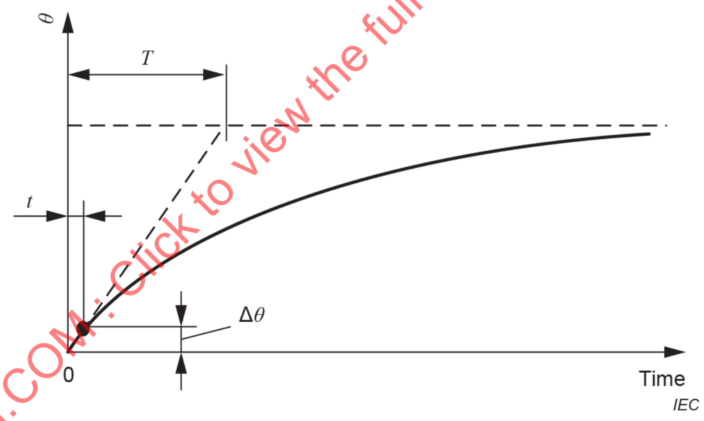
Simplified and precise methods for determining motor winding temperature cycles are included in Annex C.

C.2 Simplified method for estimation of the winding temperature deviation between maximum and mean values in one rolling cycle

The winding temperature rise is caused by copper loss, namely I^2Rt loss, due to the total current flows in the motor windings.

The synchronous motor approximate losses can be represented in terms of square of per unit motor torque current of I^2, and the temperature rise waveform can be obtained by a step response for the first order delay system with the winding thermal equivalent time constant *T*. Refer to IEC 60034-1 for determining *T* for duty cycle S9.

Figure C.1 shows the winding temperature rise waveform as a step response of the first order delay system with the winding temperature rise time constant of *T*.



Key

Δθ winding temperature deviation

t short-time overload duration time

T winding thermal equivalent time constant

θ temperature rise (K)

Figure C.1 – Winding temperature rise as a step response for the first order delay system with the winding thermal equivalent time constant of *T*

Here, the temperature rise is a steady state value (hereinafter called the "final value"), for the rated condition, and the temperature rise of the final value for the specific short-time overload condition is proportional to the square of the overload motor torque current value.

The temperature rise waveform is generally an exponential saturation curve, as is shown in Figure C.1.

However, the temperature rise $\Delta\theta$ associated with a short-time overload, in which the time period of the overload is far less than the thermal equivalent time constant T, can be approximated as a straight line. The line starts at the time the overload starts and finishes at a point determined by the final value for the temperature rise and the time corresponding to short-time overload duration.

The winding temperature deviation is defined as in formula (C.1):

$$\Delta\theta = (\theta_{\text{final}}) \times t/T \tag{C.1}$$

where

θ_{final} (K) of final value is I^2 multiplied by the winding temperature rise limit for the motor (K);

I is the overload motor torque current (p.u.);

t is the short-time overload duration time (s);

T is the thermal equivalent time constant (s).

Figure C.1 also shows the relation of the above expression.

The super-temperature θ_{sup}, which corresponds to the winding temperature difference between maximum and mean in one rolling cycle, is to be a half of the winding temperature deviation $\Delta\theta$ given by formula (C.1).Then,

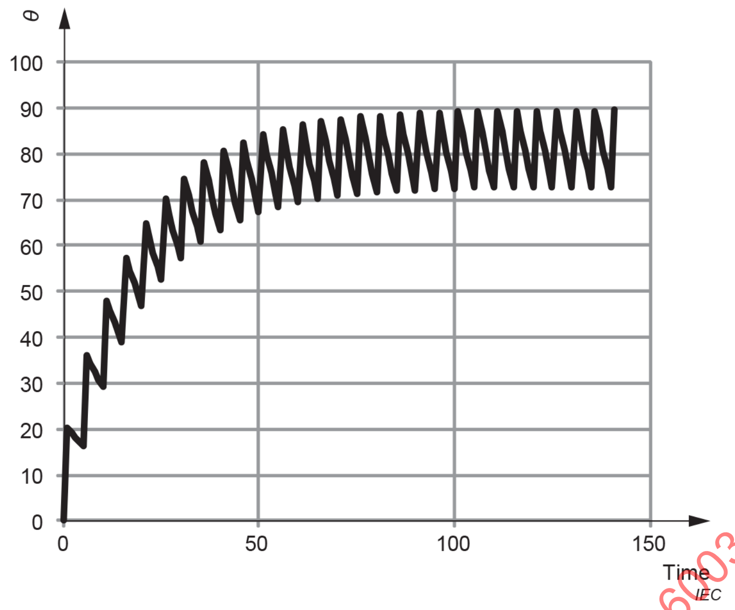
$$\theta_{\text{sup}} = \frac{1}{2} \times \Delta\theta \tag{C.2}$$

NOTE 1 In this case, $\Delta\theta$ calculated by formula (C.1) and θ_{sup} calculated by formula (C.2) are shown in Table C.1, where load duration time of 60 s and no-load duration time of 243,8 s are assumed for satisfying the condition of RMS = 1,0.

The result of formula (C.1) can be confirmed by numerical integration. The result for the transient temperature behaviour analysis is as shown in Figure C.2, for the case of repetitive 225 % overload current application for which RMS = 1,0.

Table C.1 – Calculation example for repetitive 225 % overload current with RMS = 1,0

Quantity	Symbol	Value	Unit
Current	I	2,25	per unit
Square of current	I^2	5,06	per unit
Load duration time	T_{on}	60	second (s)
No load duration time	T_{off}	243,8	second (s)
RMS		1,0	per unit
Temperature rise at rated load	θ	80	kelvin (K)
Winding temperature rise	Final value	405	kelvin (K)
	Time constant	20	minute (min)
	T_{on}	1,00	minute (min)
Temperature deviation	$\Delta\theta$	20,3	kelvin (K)
	θ_{sup}	10,1	kelvin (K)



Key

t time (min)

θ temperature rise (K)

Figure C.2 – Numerical calculation result for the condition in Table C.1

NOTE 2 The equivalent rectangular waveform approximation for the original rolling torque current waveform is necessary in advance of the application of formula (C.1).

Figure C.3 shows the principle for the approximation, where the approximated rectangular waveform is to be selected so that the I^2t for the approximated rectangular waveform can be equal to that for the original, for the overload current region for the original torque current waveform in one rolling cycle.

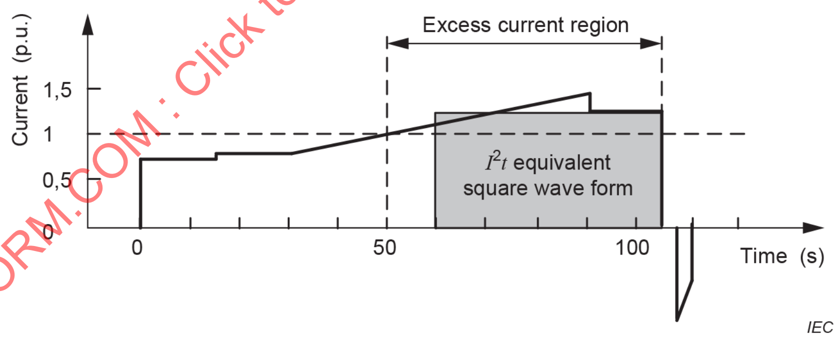


Figure C.3 – Equivalent rectangular current waveform introduction

C.3 Precise method for estimation of the winding temperature deviation between maximum and mean in one rolling cycle

For the precise method, the winding temperature deviation is calculated directly by the actual (real or scheduled) rolling load current waveform, as is shown in Figure C.4 for the finishing mill motor for a hot strip mill (HSM) [7], [8].

If the actual rolling load current I (p.u.) is normalized by the rated current, then the current square I^2 (p.u.) represents the I^2R-loss for the specific motor.

The winding temperature response can be regarded as first order delay of the I^2R-loss deviation based on the actual rolling load current waveform.

Therefore, the winding temperature response in one rolling cycle can be estimated simply by employing a first order delay and using numerical integration.

The temperature response from the above response analysis is to be in per unit.

Then the actual winding temperature deviation result can be obtained by multiplying the rated temperature rise, which is the winding temperature rise at the rated current operation for the duty type S1.

The rated temperature rise for class B should be 80 K, at the plant planning stage.

The differential equation for the first order delay system is generally described as in formula (C.3):

$$T\frac{\mathrm{d}x}{\mathrm{d}t}+x=u(t) \tag{C.3}$$

where

T is the winding temperature rise time constant (s);

x is the normalized winding temperature (p.u.);

$u(t)$ is the normalized current square I^2 (p.u.);

t is time (s).

Transposing formula (C.3), formula (C.4) is obtained:

$$\frac{\mathrm{d}x}{\mathrm{d}t}=\frac{u(t)-x}{T} \tag{C.4}$$

Formula (C.4) is a gradient of solution from the present step to the next step.

Therefore, total output solution for x against the input variable $u(t)$ can be solved by step-by-step integration, using the recursion formula in formula (C.5):

$$x_{j+1}=x_j+h\frac{\mathrm{d}x_j}{\mathrm{d}t}=x_j+h\frac{u_j-x_j}{T} \tag{C.5}$$

where

h is time step of integration (s).

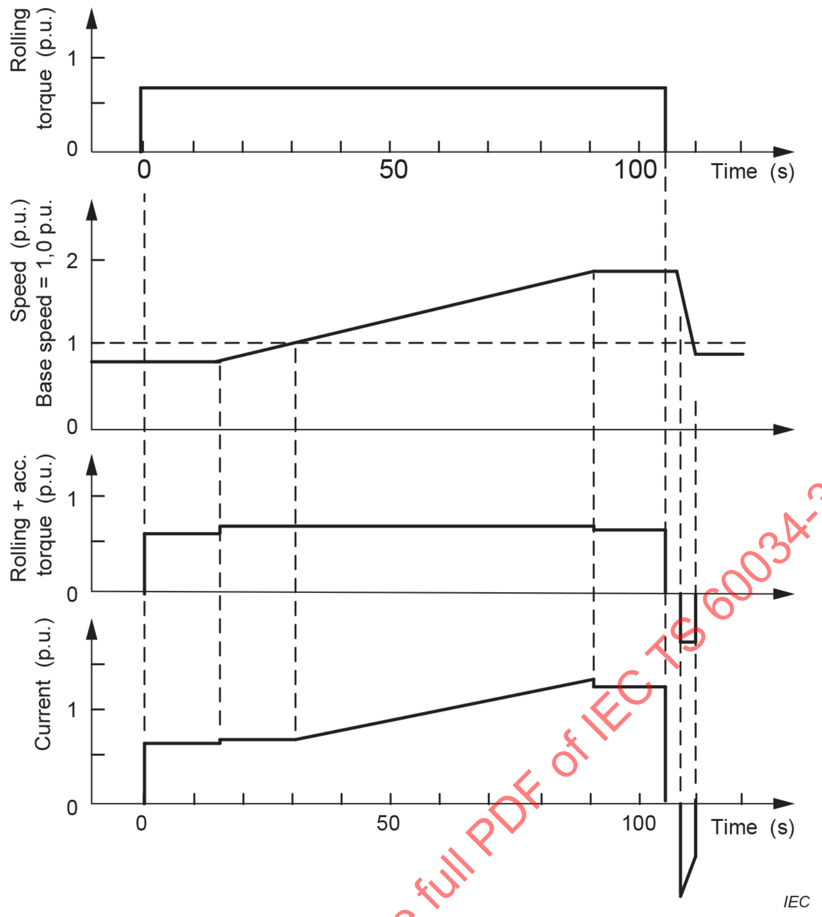


Figure C.4 – Torque, speed, and current deviation in one rolling cycle for hot strip mill finishing motor

Figure C.5 shows an example solution for the winding temperature deviation in one rolling cycle, against the rolling load current waveform shown in Figure C.4, by applying step-by-step integration by using the recursion formula of formula (C.5).

In this analysis, the waiting time for the next rolled material between 110 s and 160 s is set so that the current RMS (root mean square) value can be just 1,0 p.u.

In Table C.2, the numerical values for the temperature deviation, rolling load current variation and I^2 variation for the Figure C.5 case, are also shown.

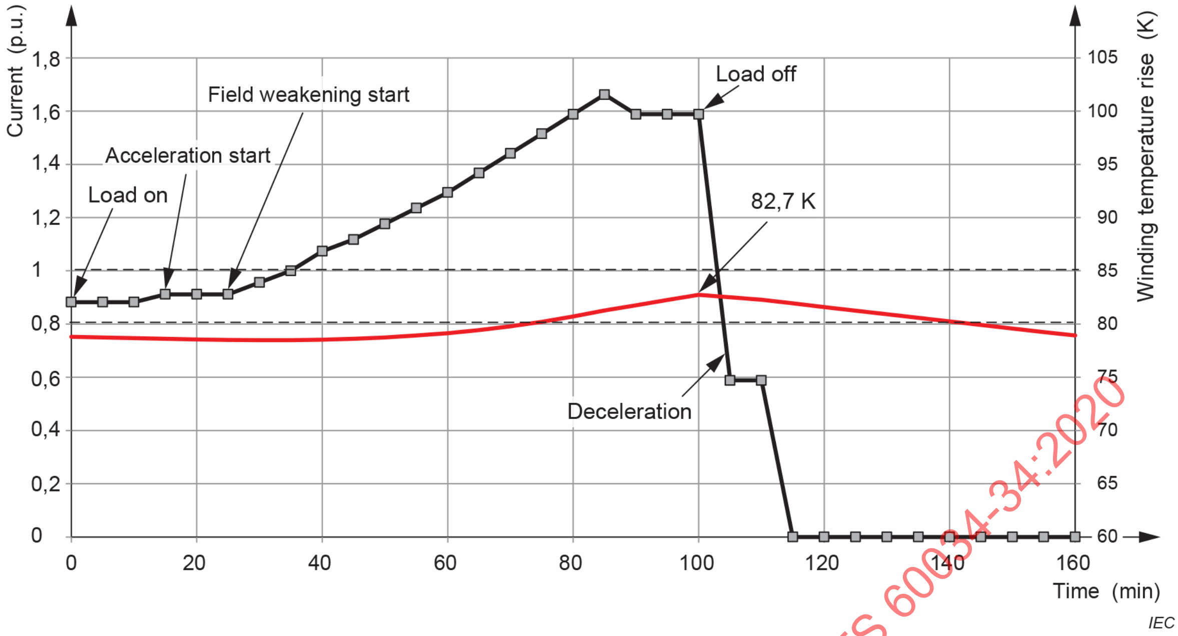


Figure C.5 – An example of winding temperature deviation estimation in one rolling cycle by the precise method

Table C.2 – An example of winding temperature deviation estimation in one rolling cycle by the precise method

Time s	Current p.u.	I^2	Winding temp. rise p.u.	Winding temp. rise K	Remarks
0	0,882	0,779	0,985	78,81	Load on
5	0,882	0,779	0,984	78,74	
10	0,882	0,779	0,983	78,67	
15	0,912	0,831	0,983	78,61	Acceleration start
20	0,912	0,831	0,982	78,56	
25	0,912	0,831	0,981	78,51	
30	0,956	0,914	0,981	78,48	
35	1,000	1,000	0,981	78,48	
40	1,074	1,152	0,982	78,53	
45	1,118	1,249	0,983	78,62	
50	1,176	1,384	0,984	78,75	
55	1,235	1,526	0,987	78,92	
60	1,294	1,675	0,989	79,14	
65	1,368	1,870	0,993	79,43	
70	1,441	2,077	0,997	79,78	
75	1,515	2,294	1,003	80,21	
80	1,588	2,522	1,009	80,70	
85	1,662	2,761	1,016	81,28	Maximum current
90	1,588	2,522	1,022	81,77	
95	1,588	2,522	1,028	82,26	
100	1,588	2,522	1,034	82,74	Maximum temperature
105	0,588	0,346	1,031	82,51	Load off
110	0,588	0,346	1,029	82,28	
115	0,0	0,0	1,024	81,94	Declaration finish
120	0,0	0,0	1,020	81,60	
125	0,0	0,0	1,016	81,26	
130	0,0	0,0	1,012	80,92	
135	0,0	0,0	1,007	80,58	
140	0,0	0,0	1,003	80,25	
145	0,0	0,0	0,999	79,91	
150	0,0	0,0	0,995	79,58	
155	0,0	0,0	0,991	79,25	
160	0,0	0,0	0,986	78,92	

Annex D
(informative)

Evaluation of reduced insulation life

Rolling mill motors experience overload torque and overload output power operation repeatedly during their useful insulation life expectancy of around 20 years. This high short-time overload torque and overload output power operation exposes the motor to increased mechanical vibration and shock impacts. The ultimate purpose of this document is to ensure long motor life under these severe operational conditions.

There is a 25 K difference between the 105 K for thermal class 155 (F) temperature rise and the 80 K for thermal class 130 (B) temperature rise by resistance method as specified in IEC 60034-1. The insulation thermal deterioration for thermal class 155 (F) insulated machine operated at thermal class 130 (B) temperature rise is decreased by approximately one sixth.

The 25 K difference is made up of one 5 K and two 10 K parts (10 K + 10 K + 5 K = 25 K) and, according to the 10 K halves insulation life law, the thermal life will be:

$$\frac{1}{2}\times\frac{1}{2}\times\frac{1}{\sqrt{2}}=\frac{1}{5,6}\approx\frac{1}{6}.$$

Stated another way, the thermal insulation life of the thermal class 155 (F) insulated machine operated at thermal class 130 (B) temperature rise would be six times the expected thermal insulation life of a thermal class 130 (B) insulated machine operated at thermal class 130 (B) rise.

On the other hand, if the thermal insulation life for AC adjustable speed rolling mill motors is considered to be principally affected by mechanical factors, such as vibration and shock loads, then, it can be concluded that the additional one sixth insulation life margin from reduced temperature rise may partially compensate for insulation degradation resulting from these mechanical factors.

Mechanical insulation deterioration is caused by the shear stress between insulation layers due to the heat expansion rate difference between copper and steel. The repetitive bending stresses caused by rapid current changes where the stator coil end turns exit the stator iron core are also considered to contribute to the mechanical insulation deterioration.

The core length for AC mill duty motors is not generally restricted by the product of output power (kW) and rotational speed (r/min) as was the case for DC mill duty motors. Therefore, common practice for AC mill duty motors is to apply them in a single motor configuration rather than multiple coupled motors. This means that heat cycle deterioration is generally more significant for AC adjustable speed rolling mill motors than with their DC counterparts.

The mechanical insulation degradation due to the repetitive bending stress in the region between the stator core and the bracing ring is also important for the insulation life analysis for the AC adjustable speed rolling mill motors. Figure D.1 shows an example of stator coil insulation surface cracks caused by repetitive mechanical stress [9].

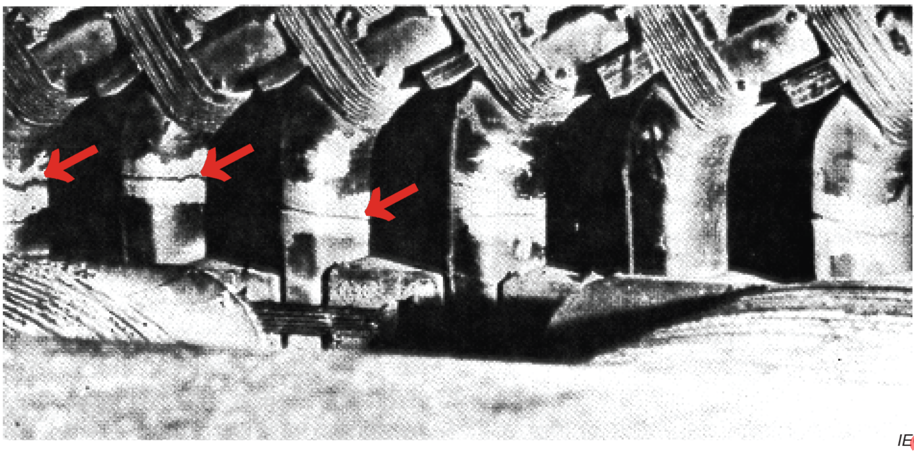


Figure D.1 – Example of stator coil insulation surface crack caused by repetitive mechanical stress

In high response AC adjustable speed drive systems, sudden changes in motor torque current can result in the electromagnetic forces exciting vibration modes in the stator coil end turns. The stator coil end turn bracing is therefore a potential mechanical weak point that requires considerable additional attention during the machine design.