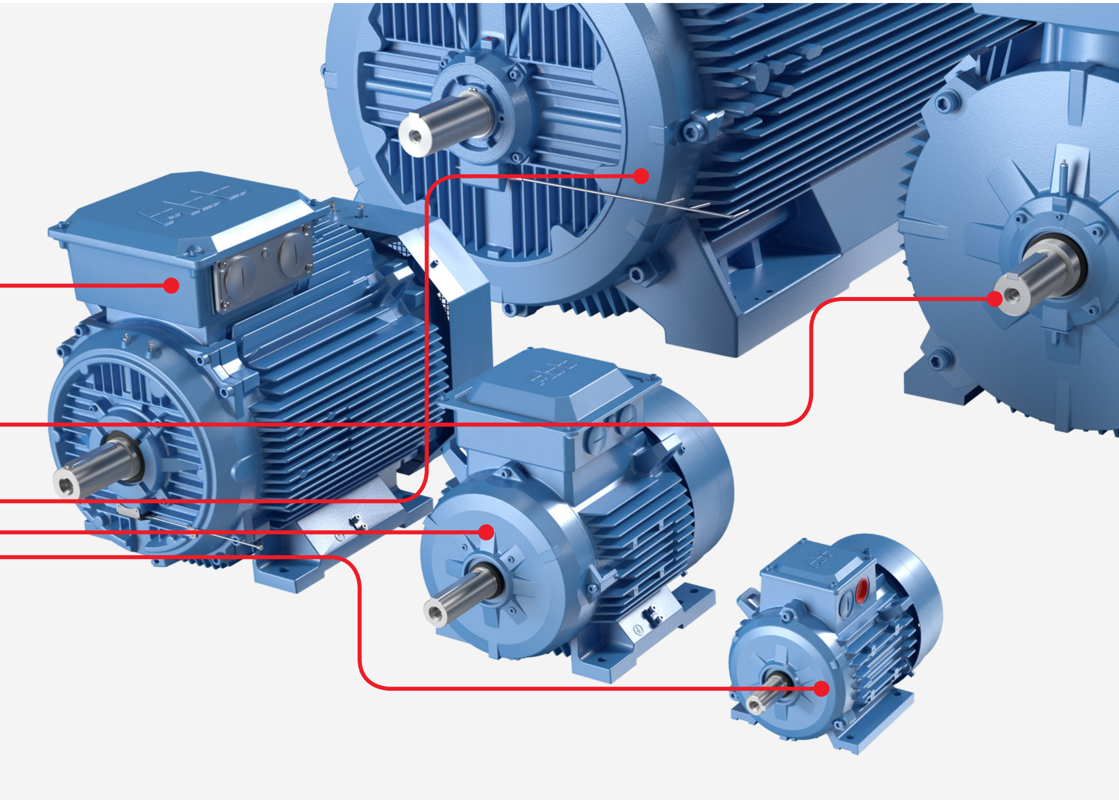
MOTOR GUIDE | OCTOBER 2018

Low voltage motors

Motor guide



We provide motors and generators, services and expertise to save energy and improve customers' processes over the total lifecycle or our products, and beyond.

Motor guide – basic technical information about low voltage standard motors

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Introduction

This guide provides basic information about IEC low voltage motors. In this context, low voltage refers to motors that operate at voltages less than 1 000 V and produce a maximum power of 1 000 kW. The reference values provided in this guide apply specifically to ABB's Process performance motor range.

The designation IEC means that the motors conform to standards developed by the International Electrotechnical Commission. For example, IEC standardizes the frame size of motors; in the case of Process performance motors, there are frame sizes starting from IEC frame 56 in the aluminum range up to 450 (millimeters from shaft to base) in the cast iron motor range. More recently, IEC standards have specified how motors should be classified into energy efficiency classes.

Introduction

1.1. About ABB

ABB is a pioneering technology leader in electrification products, robotics and motion, industrial automation and power grids, serving customers in utilities, industry and transport & infrastructure globally. Continuing a history of innovation spanning more than 130 years, ABB today is writing the future of industrial digitalization with two clear value propositions: bringing electricity from any power plant to any plug and automating industries from natural resources to finished products. As title partner of Formula E, the fully electric international FIA motorsport class, ABB is pushing the boundaries of e-mobility to contribute to a sustainable future. ABB operates in more than 100 countries with about 135,000 employees.

ABB's operations are organized into four global divisions, which in turn are made up of specific business units focused on particular industries and product categories.

1.1.1. Electrification Products

Technology across the full electrical value chain from substation to the point of consumption, enabling safer and more reliable power. A range of digital and connected innovations for low- and medium-voltage, including EV infrastructure, solar inverters, modular substations, distribution automation, power protection, wiring accessories, switchgear, enclosures, cabling, sensing and control.

1.1.2. Robotics and Motion

Motors, generators, drives, mechanical power transmission, robotics, wind and traction converters.

1.1.3. Industrial Automation

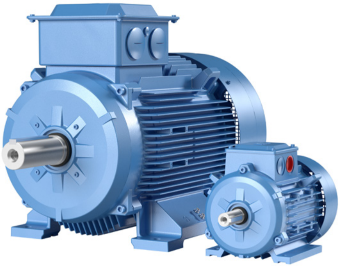
Products, systems and services designed to optimize the productivity of industrial processes. Solutions include turnkey engineering, control systems, measurement products, life cycle services, outsourced maintenance and industry specific products (eg, electric propulsion for ships, mine hoists, turbochargers and pulp testing equipment).

1.1.4. Power Grids

The Power Grids division offers power and automation products, systems, service and software solutions across the generation, transmission and distribution value chain. Its portfolio includes grid integration, transmission, distribution and automation solutions and a complete range of high voltage products and transformers.

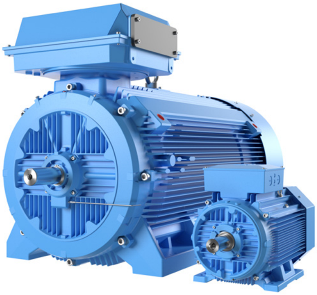
1.2. IEC low voltage motors

ABB offers wide range of low voltage motors suitable for all industries and applications, fulfilling all international and national efficiency regulations.



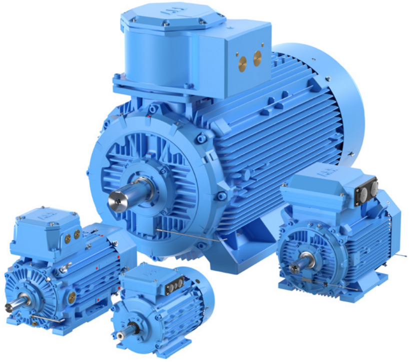
1.2.1 General performance motors

- Cast iron and aluminum motors



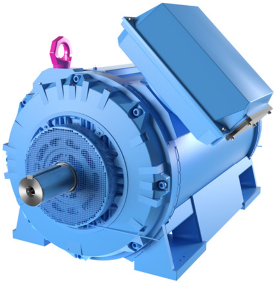
1.2.2. Process performance motors

- Process performance induction motors
- Synchronous reluctance motors
- Permanent magnet motors
- High speed motors
- Water cooled motors



1.2.3. Motors for explosive atmospheres

- Flameproof motors
- Increased safety motors
- Non-sparking motors
- Dust ignition proof motors



1.2.4. Motors for industries and specific applications

- Marine motors
- Mining motors
- Motors for food and beverage
- Motors for HVAC industry
- Motors for water and wastewater
- Brake motors
- High dynamic performance motors
- Motors for high ambient temperatures
- Roller table motors
- Smoke extraction motors
- Stainless steel motors

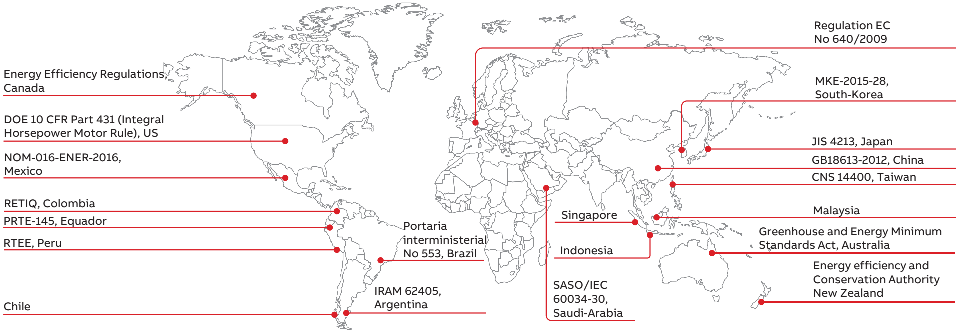
International motor efficiency

The world industry and commerce are facing an energy challenge. Global demand for energy is rising steadily. At the same time, pressures to reduce energy consumption, to lower carbon dioxide (CO_2) emissions and provide secure power supplies are becoming ever stronger.

Efficient motors help cut energy costs and limit carbon dioxide emissions. It has been estimated that electric motors account for about 65 per cent of the electricity consumed in industrial applications, so the energy-saving potential among industries is enormous. Energy consumption is dependent on the kW rating of the motor, the dimensioning of the application and the hours run. High-efficiency motors as such can play a significant part in reducing CO_2 emissions.

ABB is a long-standing advocate of the need for high efficiency in motors and its policy is to offer high-efficiency motors as standard, available directly from stock. Rather than concentrating solely on efficiency, however, we take a lifecycle approach and seek to minimize the costs associated with our products over their entire lifetime.

International motor efficiency



2.1 Standards and regulations

Since the validation of IEC 60034-30:2008 and its refined version IEC 60034-30-1:2014, a worldwide energy efficiency classification system has existed for low voltage three-phase asynchronous motors. These international standards have been created to enable and increase the level of harmonization in efficiency regulations around the world and to also cover motors for explosive atmospheres.

IEC 60034-30-1:2014 defines International Efficiency (IE) classes for single speed, three-phase, 50 Hz and 60 Hz induction motors. The efficiency levels defined in IEC 60034-30-1 are based on the test method specified in IEC 60034-2-1:2014. Both standards are part of an effort to unify motor testing procedures with CSA390-10 and IEEE 112 standards as well as efficiency and product labeling (IE) requirements to enable motor purchasers worldwide to easily recognize premium efficiency products.

To promote transparency in the market, IEC 60034-30-1 states that both the efficiency class and efficiency value must be shown on the motor rating plate and in product documentation. The documentation must clearly indicate the efficiency testing method used as different methods can produce differing results.

2.1.1 Minimum energy performance standards

While the IEC as an international standardization organization sets guidelines for motor testing and efficiency classes, the organization does not regulate efficiency levels in countries. The biggest drivers for mandatory Minimum Energy Performance Standard (MEPS) levels for electric motors are global climate change, government targets to curb CO_2 emissions and rising electricity demand, especially in developing countries. The whole value chain, from manufacturer up to end user, must be aware of the legislation in order to meet local requirements, to save energy and reduce the carbon footprint.

Harmonized global standards and the increasing adoption of MEPS around the world are good news for all of us. However, it is important to remember that harmonization is an ongoing process. Even though MEPS are already in effect in several regions and countries, they are evolving and differ in terms of scope and requirements. At the same time, more countries are planning to adopt their own MEPS regulations. A view of existing and coming MEPS regulations in the world can be seen on the World map in the previous page.

To get the latest information please visit
www.abb.com/motors&generators/energyefficiency.

2.1.2 IEC 60034-30-1:2014

This standard defines four International Efficiency (IE) classes for single speed electric motors that are rated according to IEC 60034-1 or IEC 60079-0 (explosive atmospheres) and designed for operation on sinusoidal voltage.

- IE4 = Super premium efficiency
- IE3 = Premium efficiency, identical to the table in 10CFR431 (‘NEMA Premium’) in the USA and CSA C390-10:2015 for 60 Hz
- IE2 = High efficiency
- IE1 = Standard efficiency

IEC 60034-30-1 covers the power range from 0.12 kW up to 1000 kW. Most of the different technical constructions of electric motors are covered as long as they are rated for direct on-line operation. The coverage of the standard includes:

- Single speed electric motors (single and three-phase), 50 and 60 Hz
- 2, 4, 6 and 8 poles
- Rated output PN from 0.12 kW to 1000 kW
- Rated voltage UN above 50 V up to 1 kV
- Motors capable of continuous operation at their rated power with a temperature rise within the specified insulation temperature class
- Motors, marked with any ambient temperature within the range of -20 °C to +60 °C
- Motors, marked with an altitude up to 4000 m above sea level

By comparing IEC 60034-30-1 to CSA C390-10:2015 and “10CFR431 Subpart B – Electric motors”, it can be seen that the efficiency limits and tables are well aligned and their major difference is in the scope of the output power where CSA and 10CFR431 have a maximum power of 500 hp. There are also some minor differences in the scope of excluded motors.

Note: CFR is Code of Federal Regulations.

The following motors are excluded from IEC 60034-30-1:

- Single-speed motors with 10 or more poles or multi-speed motors
- Motors completely integrated into a machine (for example pump, fan or compressor) that cannot be tested separately from the machine
- Brake motors, when the brake cannot be dismantled or separately fed

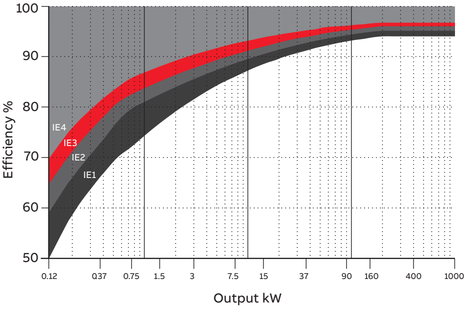


Figure 2.1

Figure 2.1 IE Classes - 4-pole motors.

2.1.3 ABB and efficiency standards

ABB determines efficiency values according to IEC 60034-2-1 using the low uncertainty method (i.e. summaration of losses), with additional load losses determined by the method of residual loss.

It is good to mention and emphasize that the IEC 60034-2-1 test method, which is known as an indirect method, is technically equivalent to the test methods in the standards CSA 390-10 and IEEE 112 Method B leading to the equivalent losses and thus efficiency values. Both test methods can be used by ABB and shall be used for both Canada and the US where IEC 60034-2-1 is not recognized yet.

As the world market leader, ABB offers the largest range of LV motors available. It has long advocated the need for efficiency in motors, and high efficiency products have formed the core of its portfolio for many years. The core of ABB’s Process performance range is based on a full range of IE2 and IE3 motors - with many available from stock. We also supply IE4 motors for additional energy savings.

Nominal efficiency limits defined in IEC 60034-30-1:2014 (reference values at 50 Hz, based on test methods specified in IEC 60034-2-1:2014).

Out-put	IE1 Standard efficiency				IE2 High efficiency				IE3 Premium efficiency				IE4 Super Premium efficiency			
kW	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole
0.12	45.0	50.0	38.3	31.0	53.6	59.1	50.6	39.8	60.8	64.8	57.7	50.7	66.5	69.8	64.9	62.3
0.18	52.8	57.0	45.5	38.0	60.4	64.7	56.6	45.9	65.9	69.9	63.9	58.7	70.8	74.7	70.1	67.2
0.20	54.6	58.5	47.6	39.7	61.9	65.9	58.2	47.4	67.2	71.1	65.4	60.6	71.9	75.8	71.4	68.4
0.25	58.2	61.5	52.1	43.4	64.8	68.5	61.6	50.6	69.7	73.5	68.6	64.1	74.3	77.9	74.1	70.8
0.37	63.9	66.0	59.7	49.7	69.5	72.7	67.6	56.1	73.8	77.3	73.5	69.3	78.1	81.1	78.0	74.3
0.40	64.9	66.8	61.1	50.9	70.4	73.5	68.8	57.2	74.6	78.0	74.4	70.1	78.9	81.7	78.7	74.9
0.55	69.0	70.0	65.8	56.1	74.1	77.1	73.1	61.7	77.8	80.8	77.2	73.0	81.5	83.9	80.9	77.0
0.75	72.1	72.1	70.0	61.2	77.4	79.6	75.9	66.2	80.7	82.5	78.9	75.0	83.5	85.7	82.7	78.4
1.1	75.0	75.0	72.9	66.5	79.6	81.4	78.1	70.8	82.7	84.1	81.0	77.7	85.2	87.2	84.5	80.8
1.5	77.2	77.2	75.2	70.2	81.3	82.8	79.8	74.1	84.2	85.3	82.5	79.7	86.5	88.2	85.9	82.6
2.2	79.7	79.7	77.7	74.2	83.2	84.3	81.8	77.6	85.9	86.7	84.3	81.9	88.0	89.5	87.4	84.5
3	81.5	81.5	79.7	77.0	84.6	85.5	83.3	80.0	87.1	87.7	85.6	83.5	89.1	90.4	88.6	85.9
4	83.1	83.1	81.4	79.2	85.8	86.6	84.6	81.9	88.1	88.6	86.8	84.8	90.0	91.1	89.5	87.1
5.5	84.7	84.7	83.1	81.4	87.0	87.7	86.0	83.8	89.2	89.6	88.0	86.2	90.9	91.9	90.5	88.3
7.5	86.0	86.0	84.7	83.1	88.1	88.7	87.2	85.3	90.1	90.4	89.1	87.3	91.7	92.6	91.3	89.3
11	87.6	87.6	86.4	85.0	89.4	89.8	88.7	86.9	91.2	91.4	90.3	88.6	92.6	93.3	92.3	90.4
15	88.7	88.7	87.7	86.2	90.3	90.6	89.7	88.0	91.9	92.1	91.2	89.6	93.3	93.9	92.9	91.2
18.5	89.3	89.3	88.6	86.9	90.9	91.2	90.4	88.6	92.4	92.6	91.7	90.1	93.7	94.2	93.4	91.7
22	89.9	89.9	89.2	87.4	91.3	91.6	90.9	89.1	92.7	93.0	92.2	90.6	94.0	94.5	93.7	92.1
30	90.7	90.7	90.2	88.3	92.0	92.3	91.7	89.8	93.3	93.6	92.9	91.3	94.5	94.9	94.2	92.7
37	91.2	91.2	90.8	88.8	92.5	92.7	92.2	90.3	93.7	93.9	93.3	91.8	94.8	95.2	94.5	93.1
45	91.7	91.7	91.4	89.2	92.9	93.1	92.7	90.7	94.0	94.2	93.7	92.2	95.0	95.4	94.8	93.4
55	92.1	92.1	91.9	89.7	93.2	93.5	93.1	91.0	94.3	94.6	94.1	92.5	95.3	95.7	95.1	93.7
75	92.7	92.7	92.6	90.3	93.8	94.0	93.7	91.6	94.7	95.0	94.6	93.1	95.6	96.0	95.4	94.2
90	93.0	93.0	92.9	90.7	94.1	94.2	94.0	91.9	95.0	95.2	94.9	93.4	95.8	96.1	95.6	94.4
110	93.3	93.3	93.3	91.1	94.3	94.5	94.3	92.3	95.2	95.4	95.1	93.7	96.0	96.3	95.8	94.7
132	93.5	93.5	93.5	91.5	94.6	94.7	94.6	92.6	95.4	95.6	95.4	94.0	96.2	96.4	96.0	94.9
160	93.8	93.8	93.8	91.9	94.8	94.9	94.8	93.0	95.6	95.8	95.6	94.3	96.3	96.6	96.2	95.1
200	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.3	95.4
250	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.5	95.4
315	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
355	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
400	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
450	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4
500-1000	94.0	94.0	94.0	92.5	95.0	95.1	95.0	93.5	95.8	96.0	95.8	94.6	96.5	96.7	96.6	95.4

2.2 Life cycle approach and energy appraisal

To achieve the best return on investment, users of production equipment need to apply a life cycle approach when considering investing in major equipment. The life cycle cost (LCC) is the total cost for purchasing, installing, operating, maintaining and disposing of an item of machinery.

It is necessary to raise awareness of the financial benefits of energy efficiency. Payback times of an item of machinery can be extremely short but many businesses still focus on the purchase price when buying new equipment, instead of considering running costs over the lifespan.

The purchase price of an electric motor and drive, for instance, is just 1-3 per cent of what the owner will spend on energy to run the equipment over its lifetime. The significance of a variable speed drive in efficiency considerations is in its quality to control the speed of the motor and therefore ensure that it runs no faster than actually needed.

LCC should be calculated not only on new installations but also existing ones. Existing systems provide much greater scope for efficiency improvements than new installations. The volume of systems in use exceeds the volume of annual new installations many times over. Additionally, many existing installations can offer considerable scope for improvement if the duty has changed since the system was first installed.

2.2.1 Energy appraisal

ABB has devised a simple and methodical energy appraisal process that presents the energy saving potential of selected applications to the end users. The starting point for an energy appraisal is to indentify applications where energy can be saved immediately.

Energy appraisals are most suitable for processes with variable torque applications that obey the cube law, run continuously, and where the flow is controlled by a mechanical means such as valves or dampers. This is where the savings from installing a variable speed drive typically are the most significant compared to the initial investment cost.

2.3 Environmental management within ABB

2.3.1 ISO 14001

To ensure continual improvement, ABB requires all manufacturing and service facilities to implement environmental management systems according to the ISO 14001 standard. For non-manufacturing sites we have implemented and adapted an environmental management system to ensure management of environmental aspects and continual performance improvement. Almost all of these approximately 360 sites and offices work in compliance with the requirements of the standard and our environmental management program now covers operations in 59 countries. It is ABB's aim to further advance the adaptation of environmental management systems among our suppliers.

2.3.2 Hazardous substances

The use of chemicals in society has increased significantly in recent decades. Concern about the negative effects of hazardous substances has resulted in stricter legal frameworks in many countries. Full control of hazardous substances in our products and processes is therefore business critical.

ABB is committed to phasing out the use of hazardous substances in our products and processes, where technically and economically feasible. We have developed lists of prohibited and restricted substances to guide this process and update them regularly, in line with developments in international regulations. Such restrictions include for example components containing brominated flame retardants, PCB, PCT or mercury, or the use of cadmium in surface treatment.

2.3.3 Materials selection

Some of the sustainability activities concerning motor production are the guidelines for selecting construction materials:

- Aim at minimizing the quantity of materials in order to reduce the weight of the product.
- Reduce the number of different materials in the product.
- Minimize the number of components used in the product and select as small components as possible.
- Choose recycled materials or a combination of virgin and recycled material for the product instead of virgin material, if possible.
- When using virgin materials, choose materials that are recyclable.
- Prefer materials for which recovery and recycling systems have been established, such as steel, aluminum, and unmixed thermoplastics.

2.3.4 EU Directive 2012/19/EU (WEEE)

The scope of the European directive 2012/19/EU for Waste Electrical & Electronic Equipment (WEEE) will extent to so called open scope from August 15, 2018. This means that also electric motors can be considered as affected by this directive.

Different member countries in EU and motor manufacturers have taken different approach in this question, some consider motors to be included and some not, and some only up to certain size.

Within our PG have we taken the decision to start marking most of the products that are produced and can be imported to Europe as described in the directive. There is also a specific recycling instruction prepared that will be delivered with the products.

Standards

ABB Motors and Generators build motors and generators to comply with international IEC and CENELEC standards. Within the European Union, ABB takes into account relevant EU-regulations, VDE-regulations, and DIN-standards. Motors conforming to other national and international specifications are also available.

All ABB motor production units are ISO 14001 certified and conform to applicable EU directives.

ABB strongly supports the drive to harmonize international standards and actively contributes to various technical committees and working groups within IEC, CENELEC and IECEx system.

Standards

3.1 Definitions

Directive
A legislative act of the European Union to achieve a particular result in the EU member states.

Standard
A specifications document established as a result of consensus between international technical experts working for a standards organization such as the International Electrotechnical Commission (IEC), the European Committee for Electrotechnical Standardization (CENELEC), or a national standards organization (NEMA in the US, DKE in Germany).

Adoption of IEC standards by any country or manufacturer is voluntary but preferred and mandatory when following the IECEx scheme.

Harmonized standard
A standard that provides conformity with corresponding requirements of an EU directive to demonstrate compliance with EU legislation.

Harmonized standards are published online under European Union's website as well as in the Official Journal (OJ) of the European Union. Their application is mandatory to the extent that a corresponding directive requires.

3.2 Standards tables

The following tables serve as reference lists for electrical and mechanical standars that apply to most induction motors depending on motor type and type of protection.

3.2.1 The main standards for low voltage motors

Electrical	Title
IEC / EN 60034-1	Rating and performance
IEC / EN 60034-2-1	Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)
IEC / EN 60034-2-2	Specific methods for determining separate losses of large machines from tests – Supplement to IEC 60034-2-1
IEC 60034-2-3	Rotating electrical machines – Part 2–3: Specific testing methods for determining losses and efficiency of converter-fed AC induction motors.
IEC / EN 60034-8	Terminal markings and direction of rotation
IEC / EN 60034-12	Starting performance of single-speed three-phase cage induction motors
IEC / TS 60034-25	Guidance for the design and performance of AC motors specifically designed for converter supply
IEC / EN 60034-26	Effects of unbalanced voltages on the performance of three-phase cage induction motors
IEC / EN 60034-30	Efficiency classes of single-speed three-phase cage induction motors (IE-Code)
IEC / TS 60034-31 CLC/TS 60034-31	Selection of energy-efficient motors including variable speed applications – Application guide
IEC 60038	IEC standard voltages
IEC 60050-411	International electrotechnical vocabulary – Chapter 411: Rotating machines

Mechanical	Title
IEC / EN 60034-5	Degrees of protection provided by the integral design of rotating electrical machines (IP code) - Classification
IEC / EN 60034-6	Methods of cooling (IC code)
IEC / EN 60034-7	Classification of types of construction, mounting arrangements and terminal box position (IM Code)
IEC / EN 60034-9	Noise limits
IEC / EN 60034-14	Mechanical vibration of certain machines with shaft heights 56 mm and higher - Measurement, evaluation and limits of vibration severity
IEC / EN 60072-1	Dimensions and output series for rotating electrical machines Part 1: Frame sizes 56 to 400 and flange numbers 55 to 1080
IEC / EN 60529	Degree of protection provided by enclosure (IP Code)
EN 50102	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)
EN 50347	General purpose three-phase induction motors having standard dimensions and outputs - Frame sizes 56 to 315 and flange numbers 65 to 740
ISO 21940-32	Mechanical vibration – rotor balancing – Part 32: Shaft and fitment key convention

Specific applications in addition to the standards above

Smoke extraction motors	Title
EN 12101-3	Smoke and heat control systems Specification for powered smoke and heat exhaust ventilators

Hazardous areas	Title
IEC / EN 60079-0	Equipment - General requirements
IEC / EN 60079-1	Equipment protection by flameproof enclosures “d”
IEC / EN 60079-7	Equipment protection by increased safety “e”
IEC / EN 60079-31	Equipment dust ignition protection by enclosure “t”
IEC / EN 60079-14	Electrical installations design, selection and erection
IEC / EN 60079-17	Electrical installations inspections and maintenance
IEC / EN 60079-19	Equipment repair, overhaul and reclamation
IEC / EN 60050-426	International electrotechnical vocabulary- Part 426: Equipment for explosive atmospheres
IEC / EN 60079-10-1	Classification of areas – Explosive gas atmospheres
IEC / EN 60079-10-2	Classification of areas – Combustible dust atmospheres

3.2.2 The main EU directives for motors

Directive	Field of application
2014/34/EU ‘ATEX’	Equipment and protective systems intended for use in potentially explosive atmospheres
1999/92/EC ‘Worker Directive’	Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres
2014/35/EU ‘Low Voltage Directive’	Making available on the market of electrical equipment designed for use within certain voltage limits (except for those used in potentially explosive atmospheres)
2009/125/EC ‘Ecodesign Directive’	Framework for the setting ecodesign requirements for energy-related products (ErP)
EU Regulation 640/2009 and amending Regulation 4/2014	Implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors

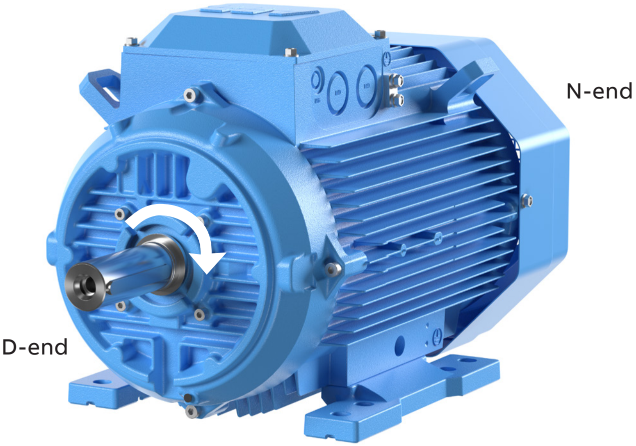
3.2.3 Efficiency determination for motors outside Europe

USA	IEEE 112-B CSA C390-10	Test procedure for polyphase induction motors and generators Test methods, marking requirements, and energy efficiency levels for tree-phase induction motors
Canada	CSA C390-10	Test methods, marking requirements, and energy efficiency levels for tree-phase induction motors
China	GB/T 1032: 2005	Test methods for induction motors; includes methods identical to IEC 60034-2-1: 2007 with segregated losses
India	IS 12615: 2011	Methods identical to IEC 60034-2-1: 2007 (in line with IEC 60034-30: 2008)
Brazil	ABNT NBR 17094-1:2013	Three-phase induction motors – Tests
Australia, New Zealand	AS/NZS 1359.102.3 or IEC 60034-2-1 AS/NZS 1359.102.1 or IEC 60034-2	Method A for determining losses and efficiency – Three-phase cage induction motors Method B for determining losses and efficiency – Three-phase cage induction motors

3.3 Direction of rotation

Motor cooling is independent of the direction of rotation, except for certain larger two-pole motors.

When the mains supply is connected to stator terminals marked U, V, and W of a three-phase motor and the mains phase sequence is L1, L2, L3, the motor will rotate clockwise, as viewed from the D-end. The direction of rotation can be reversed by interchanging any two of the three conductors connected to a starter switch or motor.



3.4 Cooling

A designation system concerning the method of cooling is based on the standard IEC 60034-6.

Example

IC 4 (A) 1 (A) 6

International Cooling

Circuit arrangement
0: Free circulation (open circuit)
4: Frame surface cooled

Primary coolant
A for air (omitted for simplified designation)

Method of movement of primary coolant
0: Free convection
1: Self-circulation
6: Machine-mounted independent component

Secondary coolant
A for air (omitted for simplified designation)
W for water

Method of movement of secondary coolant
0: Free convection
1: Self-circulation
6: Machine-mounted independent component
8: Relative displacement

ABB can deliver motors with the following cooling options.

IC 410: totally enclosed motors without a fan
IC 411: totally enclosed standard motors, frame-surface cooled with a fan
IC 416: totally enclosed motors with an auxiliary fan motor
IC 418: totally enclosed motors, frame -surface cooled without a fan
IC 31W: inlet and outlet pipe or duct circulated: water-cooled motors

Note:
Motors without a fan can deliver the same output power as those with a standard configuration (with a fan of their own) when installed according to IC 418.

3.5 Degrees of protection: IP code/IK code

Classifications of the degrees of protection provided by enclosures of rotating machines are based on:

- IEC / EN 60034-5 or IEC / EN 60529 for IP code
- IK code acc. to EN 50102 for standard motors. Impact test acc. to IEC 60079-0 for motors in hazardous atmospheres.

IP protection:
Protection of persons against getting in contact with (or approaching) live parts and against contact with moving parts inside the enclosure. Also protection of the machine against the ingress of solid foreign objects. Protection of machines against the harmful effects of the ingress of water.

IP 5 5

Characteristic letter

Degree of protection to persons and to parts of the motors inside the enclosure
2: Motors protected against solid objects greater than 12 mm
4: Motors protected against solid objects greater than 1 mm
5: Dust-protected motors
6: Dust-tight motors

Degree of protection provided by the enclosure with respect to harmful effects due to ingress of water
3: Motors protected against spraying water
4: Motors protected against splashing water
5: Motors protected against water jets
6: Motors protected against heavy seas
9: Motors protected against close-range high pressure, high temperature spray downs

IK code:
Classification of degrees of protection provided by enclosure for motors against external mechanical impacts.

IK 05

International mechanical protection

Characteristic group

Relation between IK code and impact energy

IK code	IK 00	IK 01	IK 02	IK 03	IK 04	IK 05	IK 06	IK 07	IK 08	IK 09	IK 10
Impact Energy Joule	*	0.15	0.2	0.35	0.5	0.7	1	2	5 ABB Standard	10	20

*not protected according to EN 50102

3.6 Standard voltage ranges

ABB provides motors for markets worldwide. To be able to meet customers' requirements, motors are designed for operation over a wide range of voltages. The most common voltage codes are S, D, E, and F. These cover the most common voltages used worldwide. Other voltage ranges are available on request.

The following table covers the most common voltage ranges.

Direct-on-line start or, with Δ-connection, also Y/Δ-start

Motor size	S		D	
	50 Hz	60 Hz	50 Hz	60 Hz
56-100	220-240 VΔ	-	380-415 VΔ	440-480 VΔ
	380-415 VY	440-480 VY	660-690 VY	-
112-132	220-240 VΔ	-	380-415 VΔ	440-480 VΔ
	380-415 VY	440-480VY	660-690 VY	-
160-450[1]	220, 230 VΔ		380, 400, 415 YΔ	440-480 VΔ
	380, 400, 415 VY	440 VY	660 VY	-
Motor size	**E**		**F**	
	50 Hz	**60 Hz**	**50 Hz**	**60 Hz**
56-100	500 VΔ	[2]	500 VY	[2]
112-132	500 VΔ	[2]	500 VY	[2]
160-450	500 VΔ	[2]	[2]	[2]

A chart of world voltages can be obtained from from an ABB motors sales office.

[1] The voltage range varies from type to type. Check the valid values in relevant product catalogs.
[2] On request.

Motors for other voltages

Motors wound for a given voltage at 50 Hz can also be used for other voltages. Efficiency, power factor, and speed remain approximately the same. Exact motor-specific values are available on request.

Motor wound for	230 V		400 V		500 V		690 V	
Connected to (50 Hz)	220 V	230 V	380 V	415 V	500 V	550 V	660 V	690 V
	% of values in a 400 V, 50 Hz network		% of values in a 400 V, 50 Hz network		% of values in a 400 V, 50 Hz network		% of values in a 400 V, 50 Hz network	
Output	100	100	100	100	100	100	100	100
I_N	180	174	105	98	80	75	61	58
I_S/I_N	90	100	90	106	100	119	90	100
T_S/T_N	90	100	90	106	100	119	90	100
T_{max}/T_N	90	100	90	106	100	119	90	100

3.7 Voltage and frequency

The impact on temperature rise caused by voltage and frequency fluctuation is defined in IEC 60034-1. The standard divides the combinations into two zones, A and B. Zone A is the combination of voltage deviation of +/-5 % and frequency deviation of +/-2 %. Zone B is the combination of voltage deviation of +/-10 % and frequency deviation of +3/-5 %. This is illustrated in figure 3.1.

Motors are capable of supplying the rated torque in both zones A and B, but the temperature rise will be higher than at rated voltage and frequency. Motors can be run in zone B only for a short period of time.

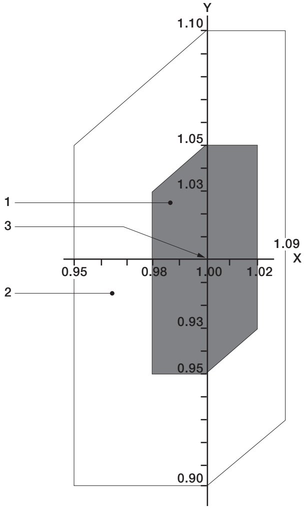


Figure 3.1 Voltage and frequency deviation in zones A and B.

Key

X axis	frequency p.u.
Y axis	voltage p.u.
1	zone A
2	zone B (outsice zone A)
3	rating point

Figure 3.1

3.8 Tolerances

In accordance with IEC 60034-1, tolerance is the maximum allowed deviation between the test result and the declared value on the rating plate (or in the catalog). Test results are based on test procedures in accordance with IEC 60034-2-2 and IEC 60034-2-3.

	Efficiency	**Power factor**	**Locked rotor current**	**Locked rotor torque**	**Pull-up torque**	**Moment of inertia**	**Noise level**
PN (kW) ≤ 150	-15 % (1-η)	-1/6 (1-cosφ)	+20 % of the current	[-15 %+25 %] of the torque	-15 % of the value	± 10 % of the value	+3 dB(A)
PN (kW) > 150	-10 % (1-η)	-1/6 (1-cosφ)	+20 % of the current	[-15 %+25 %] of the torque	-15 % of the value	± 10 % of the value	+3 dB(A)
	Slip						
PN (kW) < 1	± 30 %						
PN (kW) ≥ 1	± 20 %						

3.9 Mounting arrangements

International standards

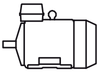
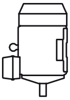
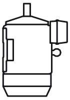
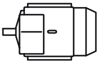
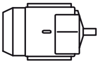
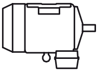
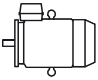
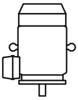
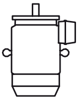
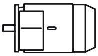
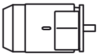
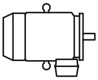
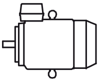
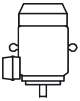
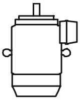
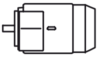
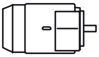
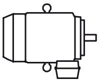
IM mounting arrangements

Example of designations according to Code II

IM **1** **00** **1**

- **IM** – Designation for international mounting
- **1** – Type of construction, foot-mounted motor with two bearing end shields
- **00** – Mounting arrangement, horizontal mounting with feet downwards etc.
- **1** – External shaft extension, one cylindrical shaft extension etc.

Examples of common mounting arrangements

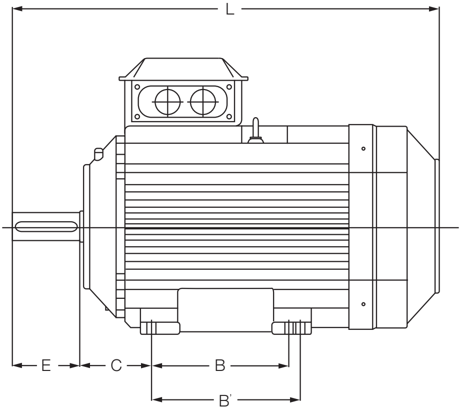
Code I	**IM B3**	**IM V5**	**IM V6**	**IM B6**	**IM B7**	**IM B8**
Code II	**IM 1001**	**IM1011**	**IM 1031**	**IM1051**	**IM 1061**	**IM 1071**
Foot-motor						
Code I	**IM B5**	**IM V1**	**IM V3**	*)	*)	*)
Code II	**IM 3001**	**IM 3011**	**IM3031**	**IM 3051**	**IM 3061**	**IM 3071**
Flange-mounted motor, large flange with clearance fixing holes.						
Code I	**IM B14**	**IM V18**	**IM V19**	*)	*)	*)
Code II	**IM 3601**	**IM 3611**	**IM 3631**	**IM 3651**	**IM 3661**	**IM 3671**
Flange-mounted motor, small flange with tapped fixing holes.						

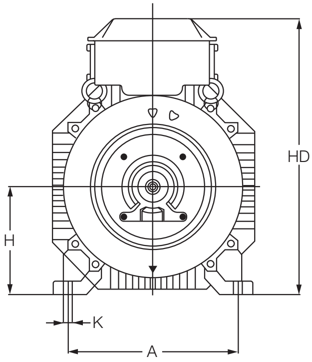
*) Not stated in IEC 60034-7

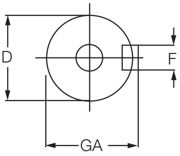
3.10 Dimensions

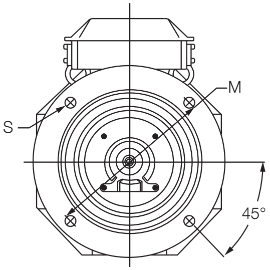
International standards IM mounting arrangements

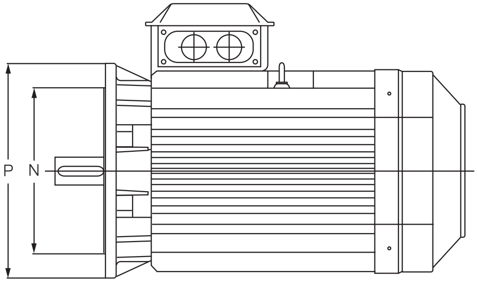
This is a sample of a typical dimension drawing. Dimension drawings are available in catalogs, and on the ABB web site.

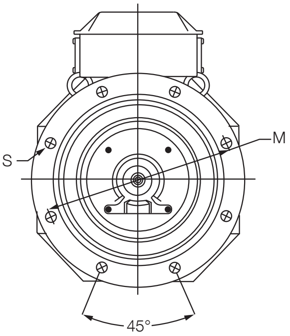












Letter symbols for the most common dimensions:

A = distance between center lines of fixing holes (end view)

B = distance between the center lines of the fixing holes (side view)

B’ = distance between the center lines of the auxiliary fixing holes

C = distance of the shoulder on the shaft at D-end to the center line of the mounting holes in the nearest feet

D = diameter of the shaft extension at D-end

E = length of the shaft extension from the shoulder at the D-end

F = width of the keyway of the shaft extension at D-end

GA = distance from the top of the key to the opposite surface of the shaft extension at D-end

H = distance from the centre line of the shaft to the bottom of the feet

HD= distance from the top of the lifting eye, the terminal box, or other most salient part mounted on the top of the motor to the bottom of the feet

K = diameter of the holes or width of the slots in the feet of the motor

L = overall length of the motor with a single shaft extension

M = pitch circle diameter of the fixing holes

N = diameter of the spigot

P = outside diameter of the flange, or in the case of a non-circular outline twice the maximum radial dimension

S = diameter of the fixing holes in the mounting flange, or nominal diameter of thread.

3.11 Output power and frame size ratio

Several countries have implemented a minimum energy efficiency performance standard (MEPS) through national legislation. IEC sets guidelines for testing and classification of motors according to standards. The following tables present two applications of power vs. frame size standards, one for Europe and another for Brazil.

In Europe, the CENELEC standard EN 50347 lays down data for rated output and mounting, i.e. shaft height, fixing dimensions and shaft extension dimensions, for various degrees of protection and sizes. It covers totally enclosed fan-cooled squirrel-cage motors at 50 Hz, frame sizes 56 M to 315 M.

Table 3.1
Power - frame size correlation according to CENELEC

Standard output								
Frame size	**Shaft extension diameter**		**Rated output**				**Flange number**	
	2 poles mm	**4,6,8 poles mm**	**2 poles kW**	**4 poles kW**	**6 poles kW**	**8 poles kW**	**Free holes (FF)**	**Tapped holes (FT)**
56	9	9	0.09 or 0.12	0.06 or 0.09			F100	F65
63	11	11	0.18 or 0.25	0.12 or 0.18			F115	F75
71	14	14	0.37 or 0.55	0.25 or 0.37			F130	F85
80	19	19	0.75 or 1.1	0.55 or 0.75	0.37 or 0.55		F165	F100
90S	24	24	1.5	1.1	0.75	0.37	F165	F115
90L	24	24	2.2	1.5	1.1	0.55	F165	F115
100L	28	28	3	2.2 or 3	1.5	0.75 or 1.1	F215	F130
112M	28	28	4	4	2.2	1.5	F215	F130
132S	38	38	5.5 or 7.5	5.5	3	2.2	F265	F165
132M	38	38	-	7.5	4 or 5.5	3	F265	F165
160M	42	42	11 or 15	11	7.5	4 or 5.5	F300	F215
160L	42	42	18.5	15	11	7.5	F300	F215
180M	48	48	22	18.5	-	-	F300	
180L	48	48	-	22	15	11	F300	
200L	55	55	30 or 37	30	18.5 or 22	15	F350	
225S	55	60	-	37	-	18.5	F400	
225M	55	60	45	45	30	22	F400	
250M	60	65	55	55	37	30	F500	
280S	65	75	75	75	45	37	F500	
280M	65	75	90	90	55	45	F500	
315S	65	80	110	110	75	55	F600	
315M	65	80	132	132	90	75	F600	

Table 3.1

—
Table 3.2
Power - frame size correlation according to NBR

Brazil requires that motors imported to Brazil comply with national ABNT NBR 17094-1:2013 standards for low voltage motors. NBR 17094-1:2008 defines the frame-power relation as shown in the table below.

Power kW	Frame HP	2 poles	4 poles	6 poles	8 poles
0.18	0.25	63	63	71	71
0.25	0.33	63	63	71	80
0.37	0.50	63	71	80	90S
0.55	0.75	71	71	80	90L
0.75	1	71	80	90S	90L
1.1	1.5	80	80	90S	100L
1.5	2	80	90S	100L	112M
2.2	3	90S	90L	100L	132S
3.0	4	90L	100L	112M	132M
3.7	5	100L	100L	132S	132M
4.7	6	112M	112M	132S	160M
5.5	7.5	112M	112M	132M	160M
7.5	10	132S	132S	132M	160L
9.2	12.5	132S	132M	160M	180M/L
11.0	15	132M	132M	160M	180L
15.0	20	160M	160M	160L	180L
18.5	25	160M	160L	180L	200L
22	30	160L	180M	200L	225S
30	40	200M	200M	200L	225M
37	50	200L	200L	225M	250S
45	60	225S	225S	250S	250M
55	75	225M	225M	250M	280S
75	100	350M	250M	280S	280M
90	125	280S	280S	280M	315M
110	150	280M	280M	315M	315M
132	175	315S	315S	315M	355
150	200	315S	315S	315M	355
185	250	315S	315M	355	355
220	300	355	355	355	355
260	350	355	355	355	355
300	400	-	355	355	-
330	450	-	355	355	-
370	500	-	355	-	-

—
Table 3.2

Electrical design – induction motors

The electrical and mechanical design chapters of this guide focus on induction motors.

Designing motors that deliver good all-round performance involves a delicate balance between a number of factors which include efficiency, cost, temperature rise, vibration, noise, bearing selection, and slot and fan design. Only the correct balance will result in high quality motors which are efficient and reliable and provide a long service life.

Electrical design – induction motors

4.1 The induction motor

ABB’s low voltage induction motors are three-phase electric motors whose rotating power is based on electromagnetic induction. The current led to motor windings creates a rotating magnetic field, which induces a voltage in the rotor bars. The bars form a closed circuit where current begins to circulate, forming another magnetic field. The magnetic fields of the rotor and stator interact in such a way that the rotor starts following the magnetic field of the stator, thus producing torque.

In the nature of asynchronous motors, the rotor tends to fall behind the speed of the magnetic field in the stator. When mechanical load increases on the motor shaft, the difference in speed (slip) increases, and a higher torque is produced.

ABB’s low voltage induction motors cover the power range from 0.06 to 1000 kW.

Figure 4.1
Safety margins per insulation class

4.2 Insulation

ABB uses class F insulation, which, with temperature rise class B, is the most commonly required insulation system for industrial motors.

Thermal class 130 (B)
- Nominal ambient temperature 40°C
- Max. permissible temperature rise 80 K
- Hot spot temperature margin 10 K

Thermal class 155 (B)
- Nominal ambient temperature 40°C
- Max. permissible temperature rise 105 K
- Hot spot temperature margin 10 K

Thermal class 180 (H)
- Nominal ambient temperature 40°C
- Max. permissible temperature rise 125 K
- Hot spot temperature margin +15 K

The use of class F insulation with class B temperature rise gives ABB products a 25 °C safety margin. This can be exploited to increase the loading of the motor for limited periods, to operate at higher ambient temperatures or altitudes or with greater voltage and frequency tolerances. It can also be exploited to extend insulation life. For instance, already a 10 K temperature reduction has a relevant effect on insulation lifetime.

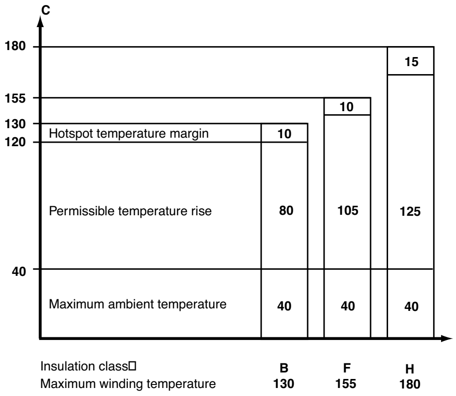


Figure 4.1

Table 4.1 Permitted output in high ambient temperatures or at high altitudes

4.3 Thermistors

Thermistors are temperature-dependent resistors inserted inside the winding heads – one for each phase – to control motor temperature. Under a certain temperature, the thermistor shows a fairly constant low resistance, but from a certain temperature upwards this resistance dramatically increases and the relay connected to thermistors will act. The resistance change is transformed into connection signals (warning or disconnection) resulting in thermal machine protection.

4.4 Ambient temperatures and high altitudes

Normal motors are designed for operation at a maximum ambient temperature of 40 °C and at a maximum altitude of 1000 meters above sea level. If a motor is operated at higher ambient temperatures, it should be derated according to the table below. Note that when the output power of a standard motor is derated, the relative values, such as I_S/I_N, in catalogs will change.

Ambient Temperature, °C	**30**	**40**	**45**	**50**	**55**	**60**	**70**	**80**
Permitted output, % of rated output	107	100	96.5	93	90	86.5	79	70

Height above sea level, m	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**
Permitted output, % of rated output	100	96	92	88	84	80	76

Table 4.1

4.5 Starting methods

The most common motor starting methods are introduced next. They are: direct-on-line and star-delta starting, and starting with a softstarter or variable speed drive.

Connection transients

It is important to remember that the term ‘starting current’ refers to a steady-state root-mean-square (rms) value. This is the value measured when, after a few cycles, the transient phenomena have died out. The peak value of the transient current may be about 2.5 times the steady-state starting current, but decays rapidly. The starting torque of the motor behaves similarly, and this should be borne in mind if the moment of inertia of the driven machine is high, since the stresses on the shaft and coupling can be great.

4.5.1 Direct-on-line (DOL) starting

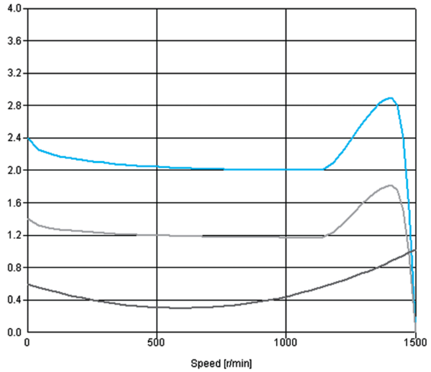
The simplest way to start a squirrel cage motor is to connect it directly to the mains supply. In this case, a switch gear e.g. a contactor is the only starting equipment required. However, the limitation of this method is that it results in a high starting current, often several times the rated current of the motor. Also the starting torque is very high, and may result in high stresses on the couplings and the driven application. Even so, it is the preferred method except when there are special reasons for avoiding it.

4.5.2 Star-delta starting

If it is necessary to restrict the starting current of a motor because of supply limitations, the star-delta (Y/Δ) method can be employed. When a motor wound for 400 V/Δ, for instance, is started with winding Y connected, this method will reduce the starting current to about 30 per cent of the current reached with DOL, and the starting torque will be reduced to about 25 per cent of its DOL value.

However, before using this method, it must be determined whether the reduced motor torque is sufficient to accelerate the load over the motor’s speed range.

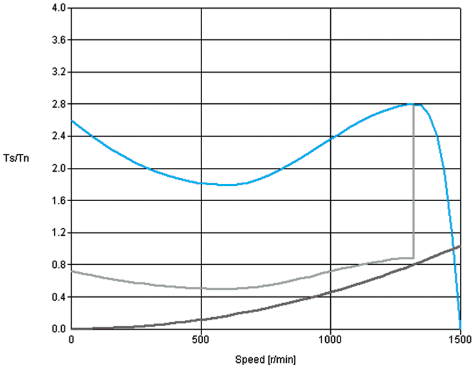
Contact your nearest ABB sales office for the MotSize dimensioning tool, or download it from our web site. ABB offers a full range of low voltage products for motor starting and control.



A sample taken from a dimensioning program
showing DOL starting curves for a cast iron motor:
1. Starting torque at U_n
2. Starting torque at 80 % U_n
3. Torque load

—

Figure 4.2



A sample taken from a dimensioning program
showing Y/Δ starting curves for an aluminum motor:
1. Starting torque at U_n
2. Starting torque at 80 % U_n
3. Torque load

—

Figure 4.3

—

Figure 4.2
DOL starting

—

Figure 4.3 Star-delta starting

4.5.3 Softstarters

A softstarter limits the starting current of the motor and so provides a smooth start. The magnitude of the starting current is directly dependent on the static torque requirement during a start and on the mass of the load to be accelerated. ABB softstarters have adjustable settings to meet any application requirements. Gradually increasing the motor voltage, and thereby torque, results in a very smooth start. When the motor is well up in speed, it is common to bypass the softstarter to avoid power loss from the semiconductors during continuous operation. To bypass the softstarter it is common to use an externally mounted, AC-1 rated contactor.

A bypass contact can also be built into the softstarter like in ABB's softstarter ranges PSR, PSE, and PSTB. These softstarters are among the most compact available in the market.

In the ABB softstarter, the main circuit is controlled by semiconductors instead of mechanical contacts. Each phase is provided with two anti-parallel connected thyristors, which allows current to be switched at any point within both positive and negative half-cycles.

Lead time is controlled by the firing angle of the thyristor which, in turn, is controlled by a built-in printed circuit board.

Figure 4.4 Impact of softstarters on current and torque

Figure 4.5 ABB softstarters

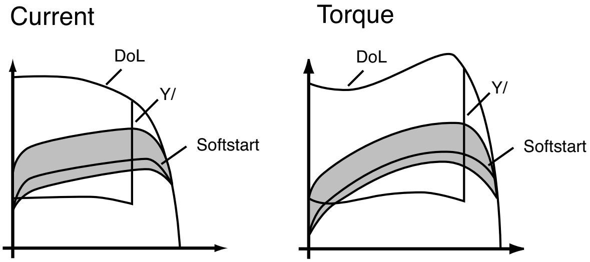


Figure 4.4

Figure 4.5

4.5.4 Starting with a variable speed drive

Speed regulation by a variable speed drive is a great advantage when there is need to adjust speed during continuous run, but it is usually not the optimal solution only for starting and stopping the motor.

With a frequency converter, the rated motor torque is available already at a low speed, and the starting current is low, between 0.5 and 1 times rated motor current, and at maximum 1.5 times nominal current. Another available feature in drives is softstop, which is useful when a smooth stop is equally desirable as a smooth start, for example in operating water pumps or running conveyor belts.

4.6 Starting limitations

Starting time

Starting time is a function of load torque, inertia and motor torque. As the starting current is always much higher than the rated current, an excessively long starting period will cause harmful temperature rise in the motor. The high current also causes electromechanical stress on the motor.

Permitted starting time

In view of temperature rise, the starting time must not exceed the time specified in the table. The figures in the table apply to starting from normal operating temperature. When starting from cold, the figures can be doubled.

Table 4.2 Maximum starting times in seconds for occasional starting, single-speed motors

		Number of poles			
Motor size	**Starting method**	**2**	**4**	**6**	**8**
56	DOL	25	40	NA	NA
63	DOL	25	40	NA	NA
71	DOL	20	20	40	40
80	DOL	15	20	40	40
90	DOL	10	20	35	40
100	DOL	10	15	30	40
112	DOL	20	15	25	50
	Y/D	60	45	75	150
132	DOL	15	10	10	60
	Y/D	45	30	30	20
160	DOL	15	15	20	20
	Y/D	45	45	60	60
180	DOL	15	15	20	20
	Y/D	45	45	60	60
200	DOL	15	15	20	20
	Y/D	45	45	60	60
225	DOL	15	15	20	20
	Y/D	45	45	60	60
250	DOL	15	15	20	20
	Y/D	45	45	60	60
280	DOL	15	18	17	15
	Y/D	45	54	51	45
315	DOL	15	18	16	12
	Y/D	45	54	48	36
355	DOL	15	20	18	30
	Y/D	45	60	54	90
400	DOL	15	20	18	30
	Y/D	45	60	54	90
450	DOL	15	20	18	30
	Y/D	45	60	54	90

Table 4.2

Permitted frequency of starting and reversing

When a motor is subjected to frequent starting, it cannot be loaded at its rated output because of thermal starting losses in the windings. Calculating the permissible output power can be based on the number of starts per hour, the moment of inertia of the load, and the speed of the load. Mechanical stresses may also impose a limit below that of thermal factors.

Permitted output power P = $P_N\sqrt{1-\frac{m}{m_o}}$

P_N = rated output of motor in continuous duty

m = $\frac{(J_M + J'_L)}{J_m}$ x X

X = number of starts per hour

J_M = moment of inertia of motor in kgm^2

J'_L = moment of inertia of load in kgm^2, recalculated for the motor shaft, i.e. multiplied by (load speed /motor speed)2. The moment of inertia J (kgm^2) equals ¼ GD2 in kpm^2.

m_o = highest permitted number of starts per hour for motor at no load, as stated in the table at right.

Highest permitted number of reversals per hour at no load mr = m_0 /4.

Table 4.3 Highest permitted number of starts/hour at no load, m_0

	Number of poles			
Motor size	**2**	**4**	**6**	**8**
56	12000	9000	-	-
63 A, B	11200	8700	-	-
71 A, B	9100	8400	16800	15700
80 A, B	5900	8000	16800	11500
90 L	3500	7000	12200	11500
100 L	2800	-	8400	-
112 M	1700	6000	9900	16000
132 M	1700	2900	4500	6600
160 ML	650	-	-	5000
180 ML	400	1100	-	-
200 ML	385	-	1900	-
225 SM	-	900	-	2350
250 SM	300	900	1250	2350
280 SM, ML	125	375	500	750
315 SM, ML	75	250	375	500
355 SM, ML, LK	50	175	250	350
400 L, LK	50	175	250	350
450 L	On request			

Table 4.3

Starting characteristics

Catalogs usually state the maximum starting time as a function of motor size and speed. However, the standard IEC 60034-12 specifies the permitted moment of inertia of the driven machine instead of starting time. For small motors, the thermal stress is greatest in the stator winding, whereas for larger motors it is greatest in the rotor winding.

If the torque curves for the motor and the load are known, the starting time can be calculated with the following equation.

$$T_M - T_L = (J_M + J_L) \times \frac{d\omega}{dt}$$

where

T_M = motor torque, Nm
T_L = load torque, Nm
J_M = moment of inertia of the motor, kgm^2
J_L = moment of inertia of the load, kgm^2
ω = angular velocity of the motor

In case of gearing T_L and J_L will be replaced by T'_L and J'_L respectively. If the starting torque T_S and maximum torque T_{max} of the motor, together with the nature of the load, are known, the approximate starting time can be calculated with the following equation.

$$t_{st} = \frac{(J_M + J'_L)}{T_{acc}} \times K_1$$

where

t_{st} = starting time, s
T_{acc} = acceleration torque, Nm
K_1 = speed constant ($2\varphi\frac{f}{p}$) where p represents the number of pole pairs

—
Table 4.4 Speed constant K_1 as a function of frequency and pole pairs.

	Poles					Frequency Hz
Speed constant	**2**	**4**	**6**	**8**	**10**	
n_m	3000	1500	1000	750	600	
K_1	314	157	104	78	62	50
n_m	3600	1800	1200	900	720	
K_1	377	188	125	94	75	60

—
Table 4.4

The average value for T_M:

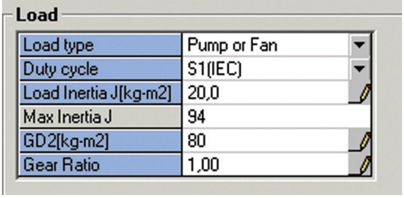
$$T_M = 0.45 \times (T_s + T_{max})$$

$$T_{acc} = T_M - K_L \times T_L$$

K_L can be obtained from the table below:

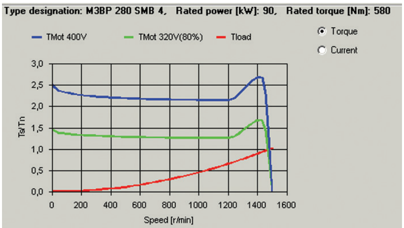
	Lift motion	Fan	Piston pump	Flywheel
K_L	1	1/3	0.5	0

Examples from the ABB calculation program on starting time



Load

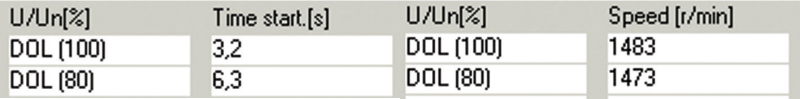
Load type	Pump or Fan
Duty cycle	S1(IEC)
Load Inertia J[kg-m2]	20,0
Max Inertia J	94
GD2[kg-m2]	80
Gear Ratio	1,00



Type designation: M3BP 280 SMB 4, Rated power [kW]: 90, Rated torque [Nm]: 580

● Torque

○ Current



U/Un[%]	Time start.[s]	U/Un[%]	Speed [r/min]
DOL (100)	3,2	DOL (100)	1483
DOL (80)	6,3	DOL (80)	1473

If there is gearing between the motor and the driven machine, the load torque must be recalculated to motor speed with the following formula.

$$T'_L = T_L \times \frac{n_L}{n_M}$$

The moment of inertia must also be recalculated:

$$J'_L = J_L \times \left(\frac{n_L}{n_M}\right)^2$$

Examples of starting performance with various load torques

4-pole motor, 160 kW, 1475 r/min

Torque of the motor

T_N = 1040 Nm
T_s = 1.7 x 1040 = 1768 Nm
T_{max} = 2.8 x 1040 = 2912 Nm
Moment of inertia of motor: $J_M = 2.5$ kgm^2
The load is geared down in a ratio of 1:2

Torque of the load

T_L = 1600 Nm at $n_L = n_M/2$ r/min
T'_L = 1600 x 1/2 = 800 Nm at n_M r/min

Moment of inertia of the load

J_L = 80 kgm^2 at $n_L = n_M/2$ r/min
J'_L = 80 x $(½)^2$ = 20 kgm^2 at n_M r/min

Total moment of inertia

$J_M + J'_L$ at n_M r/min
2.5 + 20 = 22.5 kgm^2

Example 1:

$T_L \quad = \quad 1600 \text{ Nm}$

$T'_L \quad = \quad 800 \text{ Nm}$

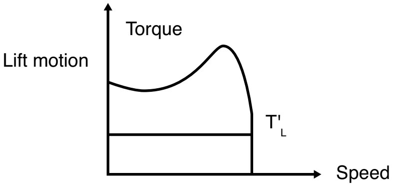
Constant during acceleration

$T_{acc} \quad = \quad 0.45 \text{ x } (T_S + T_{max}) - T'_L$

$T_{acc} \quad = \quad 0.45 \text{ x } (1768 + 2912) - 800 = 1306 \text{ Nm}$

$$t_{st} \quad = \quad \frac{(J_M + J'_L)}{T_{acc}} \text{ x } K_1$$

$$t_{st} \quad = \quad \frac{22.5 \text{ x } 157}{1306} = 2.7 \text{ s}$$



Example 2:

$T_L \quad = \quad 1600 \text{ Nm } T'_L = 800 \text{ Nm}$

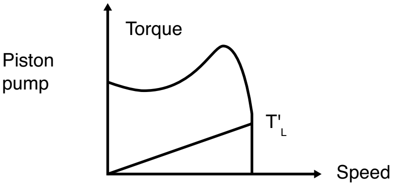
Linear increase during acceleration

$T_{acc} \quad = \quad 0.45 \text{ x } (T_S + T_{max}) – ½ \text{ x } T'_L$

$T_{acc} \quad = \quad 0.45 \text{ x } (1768 + 2912) – ½ \text{ x } 800 = 1706 \text{ Nm}$

$$t_{st} \quad = \quad (J_M + J'_L) \text{ x } K_1/T_{acc}$$

$$t_{st} \quad = \quad 22.5 \text{ x } \frac{157}{1706} = 2.1 \text{ s}$$



Example 3:

$T_L \quad = \quad 1600 \text{ Nm } T'_L = 800 \text{ Nm}$

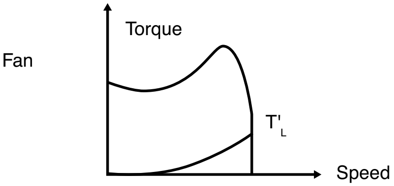
Square-law increase during acceleration

$T_{acc} \quad = \quad 0.45 \text{ x } (T_S + T_{max}) – ⅓ \text{ x } T'_L$

$T_{acc} \quad = \quad 0.45 \text{ x } (1768 + 2912) – ⅓ \text{ x } 800 = 1839 \text{ Nm}$

$$t_{st} \quad = \quad \frac{(J_M + J'_L)}{T_{acc}} \text{ x } K_1$$

$$t_{st} \quad = \quad \frac{22.5 \text{ x } 157}{1839} = 1.9 \text{ s}$$



Example 4:

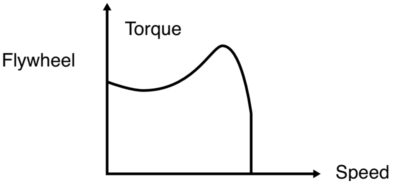
$T_L \quad = \quad 0$

$T_{acc} \quad = \quad 0.45 \text{ x } (T_S + T_{max})$

$T_{acc} \quad = \quad 0.45 \text{ x } (1768 + 2912) = 2106 \text{ Nm}$

$$t_{st} \quad = \quad \frac{(J_M + J'_L)}{T_{acc}} \text{ x } K_1$$

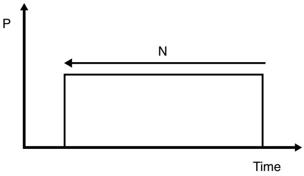
$$t_{st} \quad = \quad \frac{22.5 \text{ x } 157}{2106} = 1.7 \text{ s}$$



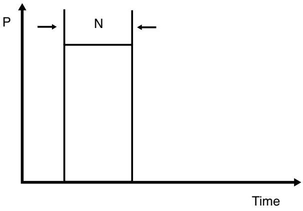
4.7 Duty types

The duty types are indicated by S1...S10 according to IEC 60034-1 and VDE 0530 Part 1. The outputs given in the catalogs are based on continuous running duty, S1, with rated output. In the absence of an indication of the rated duty type, continuous running duty is assumed when considering motor operation.

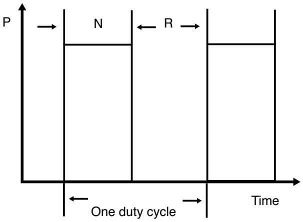
S1 Continuous running duty
Operation on constant load of sufficient duration for thermal equilibrium to be reached. Designation S1.



S2 Short-time duty
Time shorter than that required to reach thermal equilibrium, followed by a rest and a de-energized period of sufficient duration to allow motor temperature to reach ambient termperature or cooling temperature. 10, 30, 60, and 90 minutes are recommended for the rated duration of the duty cycle. Designation for example S2 60 min.



S3 Intermittent duty
A sequence of identical duty cycles, each including a period of operation at constant load, a rest and a de-energized period. The duty cycle is too short for thermal equilibrium to be reached. The starting current does not significantly affect temperature rise. Recommended values for the cyclic duration factor are 15, 25, 40, and 60 percent. The duration of one duty cycle is 10 min. Designation for example S3 25 %.

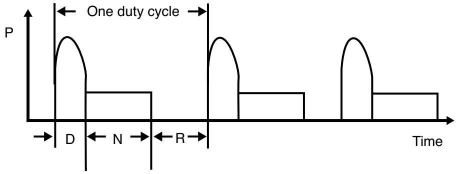


$$\text{Cyclic duration factor} = \frac{N}{N + R} \times 100\ \%$$

Explanation of symbols used in this and the following figures

P = output power
D = acceleration
N = operation under rated condition
F = electrical braking
V = operation of no load
R = at rest and de-energized
P_N = full load

S4 Intermittent duty with starting

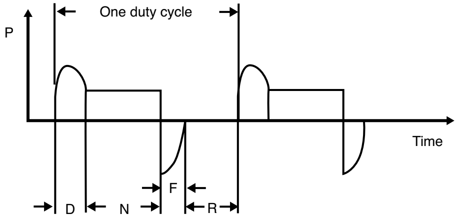


A sequence of identical duty cycles, each cycle including a significant period of starting, operation at constant load, a rest and a de-energized period. The cycle-time is too short for thermal equilibrium to be reached. In this duty type, the motor is brought to rest by the load or by mechanical braking which does not thermally load the motor. The following parameters are required to fully define the duty type: the cyclic duration factor, the number of duty cycles per hour (c/h), the moment of inertia of the load (J_L) and the moment of inertia of the motor (J_M).

Designation for example S4 25 % 120 c/h $J_L = 0.2$ kgm2 $J_M = 0.1$ kgm^2.

$$\text{Cyclic duration factor} = \frac{D + N}{D + N + R} \times 100\ \%$$

S5 Intermittent duty with starting and electrical braking



A sequence of identical duty cycles, each cycle consisting of a significant starting period, a period of operation at constant load, a period of rapid electric braking, a rest and a de-energized period. The duty cycles are too short for thermal equilibrium to be reached. The following parameters are required to fully define the duty type: the cyclic duration factor; the number of duty cycles per hour (c/h), the moment of inertia of the load (J_L) and the moment of inertia of the motor (J_M).

Designation for example S5 40 % 120 c/h $J_L = 2.6$ kgm^2 $J_M = 1.3$ kgm^2.

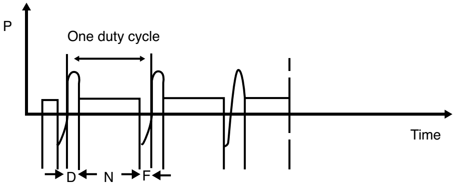
$$\text{Cyclic duration factor} = \frac{D + N + F}{D + N + F + R} \times 100\ \%$$

S6 Continuous operation periodic duty

A sequence of identical duty cycles, each cycle consisting of a period at constant load and a period of operation at no-load. The duty cycles are too short for thermal equilibrium to be reached. Recommended values for the cyclic duration factor are 15, 25, 40, and 60 percent. The duration of the duty cycle is 10 min.

Designation for example S6 40 %. Cyclic duration factor = $100\ \% \times \dfrac{N}{N + V}$

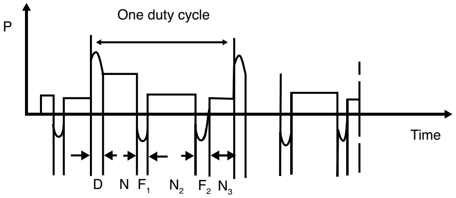
S7 Continuous operation periodic duty with electrical braking



A sequence of identical duty cycles, each cycle consisting of a starting period, a period of operation at constant load, and a period of braking. The braking method is electrical braking such as counter-current braking. The duty cycles are too short for thermal equilibrium to be reached. The following parameters are required to fully define the duty type: the number of duty cycles per hour (c/h), the moment of inertia of the load (J_L), and the moment of inertia of the motor (J_M).

Designation for example S7 500 c/h $J_L = 0.08$ kgm^2 $J_M = 0.08$ kgm^2.

S8 Continuous-operation periodic duty with related load speed changes



A sequence of identical duty cycles, each cycle consisting of a starting period, a period of operation at constant load corresponding to a predetermined speed, followed by one or more periods of operation at other constant loads corresponding to different speeds. There is no rest or a de-energized period. The duty cycles are too short for thermal equilibrium to be reached. This duty type is used for example by pole-changing motors. The following parameters are required to fully define the duty type: the number of duty cycles per hour (c/h), the moment of inertia of the load (J_L), the moment of inertia of the motor (J_M), and the load, speed, and cyclic duration factor for every operation speed.

Designation for example S8 30 c/h $J_L = 63.8$ kgm^2 $J_M = 2.2$ kgm^2.

24 kW	740 r/min	30%
60 kW	1460 r/min	30%
45 kW	980 r/min	40%

$$\text{Cyclic duration factor 1} = \frac{D + N_1}{D + N_1 + F_1 + N_2 + F_2 + N_3} \text{ x } 100\ \%$$

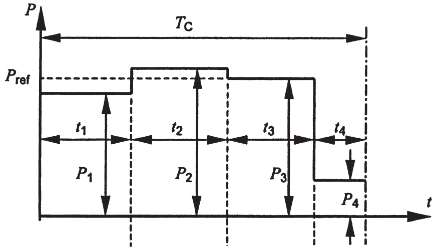
$$\text{Cyclic duration factor 2} = \frac{F_1 + N_2}{D + N_1 + F_1 + N_2 + F_2 + N_3} \text{ x } 100\ \%$$

$$\text{Cyclic duration factor 3} = \frac{F_2 + N_3}{D + N_1 + F_1 + N_2 + F_2 + N_3} \text{ x } 100\ \%$$

S9 Duty with non-periodic load and speed variations

A duty in which, generally, load and speed vary non-periodically within the permissible operating range. This duty includes frequently applied overloads that may greatly exceed the full loads. For this duty type, suitable full load values should be taken as the basis of the overload concept.

S10 Duty with discrete constant loads and speeds



A duty consisting of a specific number of discrete values of load (or equivalent loading) and if applicable, speed, each load/speed combination being maintained for sufficient time to allow the machine to reach thermal equilibrium. The minimum load within a duty cycle may have the value zero (no-load or de-energized and at rest).

The appropriate designation is S10, followed by the per-unit quantities plΔt for the respective load and its duration, and the per-unit quantity TL for the relative thermal life expectancy of the insulation system. The reference value for the thermal life expectancy is the thermal life expectancy at rating for continuous running duty and permissible limits of temperature rise based on duty type S1. For a time de-energized and at rest, the load shall be indicated by the letter r.

Example: S10 plΔt = 1.1/0.4; 1/0.3; 0.9/0.2; r/0.1 T_L = 0.6

The value of T_L should be rounded to the nearest multiple of 0.05.

For this duty type a constant load appropriately selected and based on duty type S1 shall be taken as the reference value (‘P_{ref}’ in the figure) for the discrete loads.

Note: The discrete values of load will usually be equivalent loading based on integration over a period of time. It is not necessary that each load cycle be exactly the same, only that each load within a cycle be maintained for sufficient time for thermal equilibrium to be reached, and that each load cycle is capable of being integrated to give the same relative thermal life expectantly.

4.8 Uprating

Because of the lower temperature rise in the motor in short-time or intermittent duty, it is usually possible to take higher output from the motor in these types of duty than in continuous duty, S1. The tables below show some examples of this. Attention must be paid to the motor's maximum torque, T_{max}/T_N must be >1.8 referred to increased output.

Table 4.5 Permitted output in short time duty S2 as percentage of rated output

		Permitted output as % of rated output in S1 continuous duty for motor size		
Short-time duty S2	**Poles**	56 – 100	112 - 250	280 - 450
30 min	2	105	125	130
	4 - 8	110	130	130
60 min	2 - 8	100	110	115

Table 4.5

Table 4.6 Permitted output in intermittent duty S3 as percentage of rated output

		Permitted output as % of rated output in S1 continuous duty for motor size		
Intermittent duty S3	**Poles**	56 – 100	112 - 250	280 - 450
15 %	2	115	145	140
	4	140	145	140
	6, 8	140	140	140
25 %	2	110	130	130
	4	130	130	130
	6, 8	135	125	130
40 %	2	110	110	120
	4	120	110	120
	6, 8	125	108	120
60 %	2	105	107	110
	4	110	107	110
	6, 8	115	105	110

Table 4.6

4.9 Efficiency and types of losses

Efficiency of a motor is a measure of how well it is capable of converting electrical energy into mechanical work. Lost energy is emitted in the form of heat. To increase efficiency, losses have to be reduced.

Motor losses can be divided into five main categories. The first category is iron losses in the core, the second windage and friction losses. Load losses, which vary with the load, are classified into copper losses in the stator, rotor losses, and stray load losses. All losses can be influenced by motor design and construction solutions.

Constant losses
Iron losses in the core are caused by the energy required to overcome the opposition to changing magnetic fields in the core material. These losses can be reduced by using better-quality steel and by lengthening the core to reduce magnetic flux density.

Windage and friction losses are caused by air resistance and bearing friction. Improved bearing design and bearing seal selection, air flow and fan design affect these losses. The fan must be large enough to provide adequate cooling, but not so large as to reduce efficiency and increase noise. To reach an optimal cooling effect in each ABB motor, blade sizes and pitches vary in different fan models.

Load losses
Of load losses, stator copper losses (also referred to as I2R losses) are caused by heating from the current flow through the resistance of the stator winding. Techniques for reducing these losses include optimizing the stator slot design.

Rotor losses are depending on the slip. These losses are reduced for example by increasing the size of the conductive bars and end rings to produce lower resistance. Stray load losses are the result of leakage fluxes induced by load currents. These can be decreased by improving slot geometry.

Completely new motor designs are also developed to increase efficiency beyond known limits. The synchronous reluctance motor is an example of these new designs.

Efficiency values for rated output are listed in the technical data tables in ABB product catalogs.

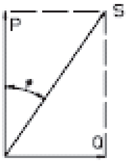
4.10 Power factor

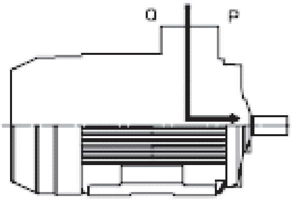
A motor consumes both active power, which it converts into mechanical work, and reactive power, which is needed for magnetization and which is not converted to work.

The active and reactive power, represented in the diagram (below) by P and Q, together give the apparent power S. The ratio between active power, measured in kW, and apparent power, measured in kVA, is known as the power factor. The angle between P and S is usually designated as φ, and the power factor itself is designated as cos φ.

Power factor is usually between 0.7 and 0.9. It is lower for small motors and higher for large motors.

Power factor is determined by measuring the input power, voltage and current at rated output power. The power factor stated is subject to a tolerance of (1-cos φ)/6 .





If there are many motors in an installation, a lot of reactive power will be consumed and therefore the power factor will be lower. For this reason, power suppliers sometimes require the power factor of an installation to be increased. This is done by connecting capacitors to the supply which absorb reactive power and thus raise the power factor.

Reactive-power compensation

With phase compensation, the capacitors are usually connected in parallel with the motor, or with a group of motors. However, in some cases, over-compensation can cause an induction motor to self-excite and run as a generator. Therefore, to avoid complications, it is a normal practice not to compensate for more than the no-load current of the motor.

The capacitors must not be connected in parallel with single phases of the winding; such an arrangement may make the motor difficult or impossible to start with star-delta starting.

If a two-speed motor with separate windings has phase compensation on both windings, the capacitors should not remain in circuit on the unused winding.

—
Table 4.7 Phase compensation

Under certain circumstances, such capacitors can cause increased heating of the winding and possibly also vibration.

The following formula is used to calculate the size (per phase) of a capacitor for a mains frequency of 50 Hz:

$$C = 3.2 \cdot 10^6 \cdot \frac{Q}{U_2}$$

Where
C = capacitance, μF
U = capacitor voltage, V
Q = reactive power, kvar.

Reactive power is obtained from:

$$Q = K \cdot P \frac{P}{\eta}$$

Where
K = constant from table on right
P = rated power of motor, kW
η = efficiency of motor

cos φ without compensation	**Constant K Compensation to cos φ =**			
	0.95	**0.90**	**0.85**	**0.80**
0.50	1.403	1.248	1.112	0.982
0.51	1.358	1.202	1.067	0.936
0.52	1.314	1.158	1.023	0.892
0.53	1.271	1.116	0.980	0.850
0.54	1.230	1.074	0.939	0.808
0.55	1.190	1.034	0.898	0.768
0.56	1.150	0.995	0.859	0.729
0.57	1.113	0.957	0.822	0.691
0.58	1.076	0.920	0.785	0.654
0.59	1.040	0.884	0.748	0.618
0.60	1.005	0.849	0.713	0.583
0.61	0.970	0.815	0.679	0.548
0.62	0.937	0.781	0.646	0.515
0.63	0.904	0.748	0.613	0.482
0.64	0.872	0.716	0.581	0.450
0.65	0.841	0.685	0.549	0.419
0.66	0.810	0.654	0.518	0.388
0.67	0.779	0.624	0.488	0.358
0.68	0.750	0.594	0.458	0.328
0.69	0.720	0.565	0.429	0.298
0.70	0.692	0.536	0.400	0.270
0.71	0.663	0.507	0.372	0.241
0.72	0.635	0.480	0.344	0.214
0.73	0.608	0.452	0.316	0.186
0.74	0.580	0.425	0.289	0.158
0.75	0.553	0.398	0.262	0.132
0.76	0.527	0.371	0.235	0.105
0.77	0.500	0.344	0.209	0.078
0.78	0.474	0.318	0.182	0.052
0.79	0.447	0.292	0.156	0.026
0.80	0.421	0.266	0.130	
0.81	0.395	0.240	0.104	
0.82	0.369	0.214	0.078	
0.83	0.343	0.188	0.052	
0.84	0.317	0.162	0.026	
0.85	0.291	0.135		
0.86	0.265	0.109		
0.87	0.238	0.082		
0.88	0.211	0.055		
0.89	0.184	0.027		
0.90	0.156			

—
Table 4.7

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Table 4.8
Power factors
for induction
motors

Power factor values

The power factors for rated output are listed in the technical data tables in product catalogs.

The table below illustrates typical power factors. ABB supplies guaranteed values on request.

As the table shows, a motor with a power factor of 0.85 has 3/4 load value of 0.81, 1/2 load value of 0.72 and 1/4 value of 0.54.

Power factor cos φ				
				2 - 12 poles
1.25 x PN	**1.00 x PN**	**0.75 x PN**	**0.50 x PN**	**0.25 x PN**
0.92	0.92	0.90	0.84	0.68
0.91	0.91	0.89	0.83	0.66
0.90	0.90	0.88	0.82	0.64
0.89	0.89	0.87	0.81	0.62
0.88	0.88	0.86	0.80	0.60
0.88	0.87	0.84	0.76	0.58
0.87	0.86	0.82	0.73	0.56
0.86	0.85	0.81	0.72	0.54
0.85	0.84	0.80	0.71	0.52
0.84	0.83	0.78	0.70	0.50
0.84	0.82	0.76	0.66	0.46
0.84	0.81	0.74	0.63	0.43
0.83	0.80	0.73	0.60	0.40
0.82	0.79	0.72	0.59	0.38
0.82	0.78	0.71	0.58	0.36
0.81	0.77	0.69	0.55	0.36
0.81	0.76	0.68	0.54	0.34
0.80	0.75	0.67	0.53	0.34
0.79	0.74	0.66	0.52	0.32
0.78	0.73	0.65	0.51	0.32
0.78	0.72	0.62	0.48	0.30
0.78	0.71	0.61	0.47	0.30
0.77	0.70	0.60	0.46	0.30

—
Table 4.8

—
Table 4.9
Air flow and
air speed

4.11 Air flow and air speed

When the motor is ordered without self-cooling, attention must be paid to ensure sufficient cooling by other means. Air flow and air speed between the ribs of the motor frame must at the minimum meet the values given in the table below. The values correspond to 50 Hz network supply; with 60 Hz supply an increase of 20 % is needed.

Shaft height	Pole number	Air speed m/s	Air flow m^3/s
280	2	9.6	0.46
	4	8.5	0.39
	6	6.5	0.32
	8	7.6	0.36
315 SM. ML	2	8.3	0.46
	4	9.4	0.56
	6	7.5	0.4
	8	7.6	0.43
315 LK	2	7.8	0.47
	4	15	0.80
	6	9.5	0.53
	8	8.8	0.49

Shaft height	Pole number	Air speed m/s	Air flow m^3/s
355	2	10	0.82
	4	13	1.1
	6	11.5	1.0
	8	8.5	0.7
400	2	15	1.4
	4	13	1.25
	6	11	1.1
	8	8	0.8
450	2	15	2.0
	4	15	2.0
	6	13	1.7
	8	10	1.25

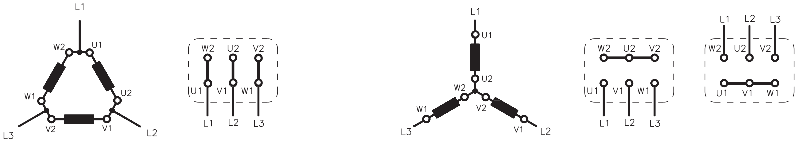
—
Table 4.9

Figure 4.6
Connection of three-phase single-speed motors

Figure 4.7
Connection options for two-speed motors

4.12 Connection diagrams

Connection of three phases, single speed motors



Y connection

Δ-connection

Figure 4.6

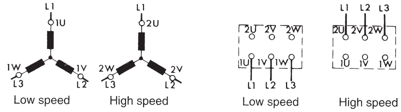
Connection of two-speed motors

Two-speed motors are normally connected as illustrated below; direction of rotation is discussed in the Standards chapter. Motors of normal design have six terminals and one earth terminal in the terminal box. Motors with two separate windings are normally Δ-Δ connected. They can also be Y/Y, Y/Δ or Δ/Y connected. Motors with one winding, Dahlander-connection, are connected Δ/YY when designed for constant torque drives. For a fan drive, the connection is Y/YY.

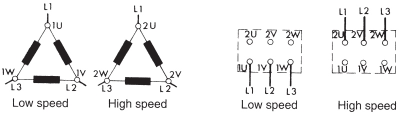
A connection diagram is supplied with every motor.

When starting a motor using Y Δ connection, always refer to the connection diagram supplied by the starter manufacturer.

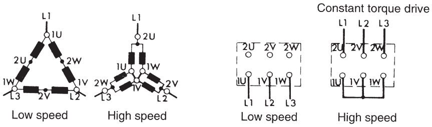
1. Two separate windings Y/Y



2. Two separate windings Δ/Δ



3. Dahlander-connection Δ/YY



4. Dahlander-connection Y/YY

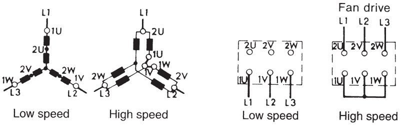


Figure 4.7

Mechanical design

This chapter introduces the main parts of an induction motor and the mechanical design of the parts that are of highest interest from motor usage point of view: the frame and terminal box, bearings, and drain holes.

The basics of radial and axial forces as well as the standards that define requirements for motor balancing, vibration measurement, and surface treatment are also discussed.

Mechanical design

5.1 Motor construction

The induction motor is an electric motor that uses electric power to induce rotation of the rotor. The main parts of the induction motor and their functions are as follows.

Stator - the stationary part of the motor which surrounds the rotor. The stator consists of copper wires (windings) wound in between the stator's slots to carry supply current and to induce a rotating magnetic field to interact with the rotor.

Rotor - the rotating core part of the motor fixed to the shaft. The rotor consists of a stack of thin steel laminations and a squirrel-cage construction of conductive bars that react with the magnetic field of the motor and produce torque to turn the shaft.

Shaft - the rotating innermost part of the motor which transmits the rotor's rotational power to the application fixed to the motor's D-end.

Bearing - bearings surround the motor's shaft at both ends and reduce friction between the motor frame and shaft.

Frame – cast-iron or aluminum casing which covers the motor's core parts and provides electrical connections.

D-end - the drive end of the motor.

N-end - the non-drive end of the motor.

—
Figure 5.1
Cross-section of a cast-iron induction motor

The following is a cross-section of a three-phase induction motor and its main parts.

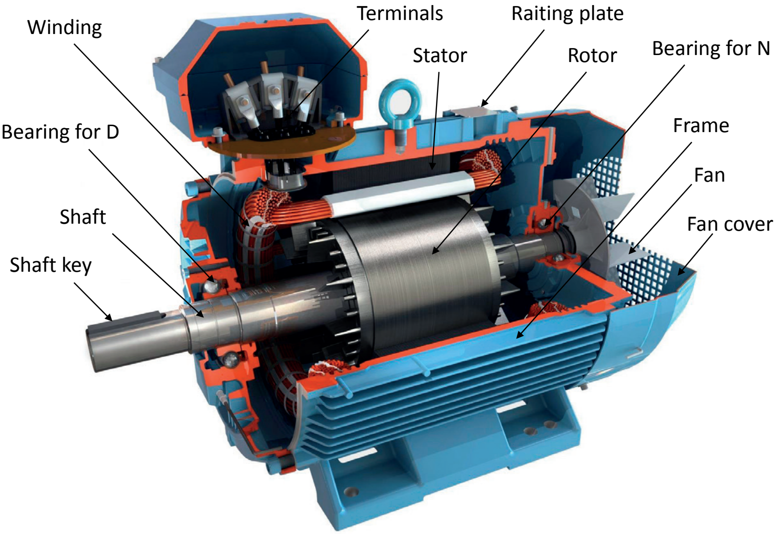


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Figure 5.1

5.2 Frame constructions

Totally enclosed electric motors are available in a choice of aluminum and cast iron frames for different application areas. Cast-iron-framed motors are typically used in heavy industries where better durability against chemicals and corrosion is required, whereas aluminum-framed motors are better suited for lighter applications such as pumps and fans.

Figure 5.2 Connection flange with cable

Figure 5.3 Angle adapter and cable-sealing glands box

5.3 Terminal boxes

The terminal box is mounted either on top of the motor or on either side of the motor. Technical details may vary from type to type, and the most recent information can be found in the relevant product catalogs.

The terminal boxes of aluminum motors in sizes 56 to 180 are normally provided with knock-out openings, and sizes 200 to 250 have terminal boxes with two gland plates.

The terminal boxes of cast-iron motors in sizes 71 to 250 are equipped with blank cover plates for connection flanges. In motor sizes 280 to 450, the terminal box is equipped with cable glands or cable boxes (Figures 5.2 and 5.3). There is a wide range of cable glands and cable boxes available as options, also equipped with EMC modules and cable clamps.

The terminal box material is either cast iron or aluminum, depending on the motor type. The main terminal box is attached either on top, on side, or at a 45 degree angle on the side. It may also be connected to the motor with extended cables, so-called flying leads. In case of accessories such as thermistors or heating elements, one or more auxiliary terminal boxes may be attached to the motor. Non-standard designs of terminal boxes, such as non-standard size and degree of protection, are available as options.

A standard motor usually has six phase connections and at least one earthing connection (Figures 5.4 and 5.5). The necessary connection parts and a connection diagram are delivered together with the motor, under the terminal box cover.

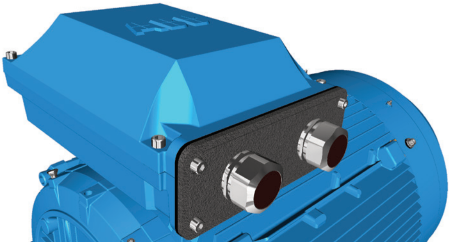


Figure 5.2

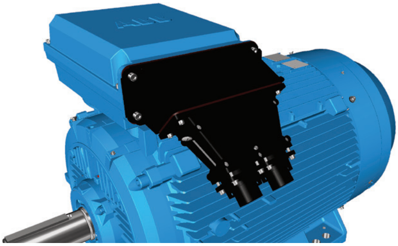
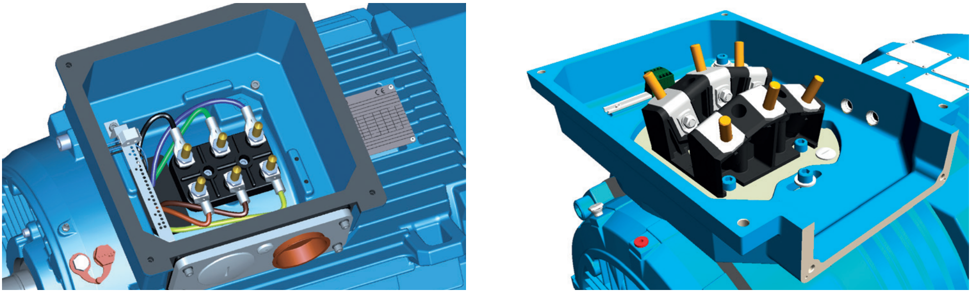


Figure 5.3



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Figures 5.4–5.5

—
Figures 5.4–5.5 Typical terminal boxes in motor sizes 71 to 250 (5.4) and 280 to 315 (5.5)

—
Figure 5.6 Terminal box integrated in motor frame

The terminal box in aluminum motors allows cable entry from both sides. In small motors, the box is integrated in motor frame and has a blind flange on with knock-out openings on both sides (Figure 5.6). Larger aluminum motors are equipped with two connection flanges on both sides. In cast iron motor sizes 71 – 132, the box is integrated in the frame, with connection on the right-hand side (viewed from the D-end). Sizes 160 – 355 have a terminal box that can be rotated 4x90°, and sizes 400 – 450 have a terminal box that can be rotated 2x180° to allow cable entry from either side of the motor. The 4x90° turnable box is available as an option for several other motor types as well.

The degree of protection of a standard terminal box is IP 55.

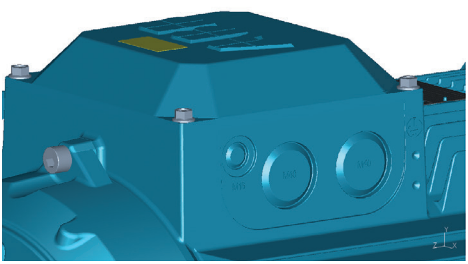

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Figure 5.6

To ensure that suitable connections are supplied for the terminal box, see the specific product catalog for information on flange openings, cable diameters, and so forth.

5.4 Bearings

Motors are normally fitted with single row deep groove ball bearings. The complete bearing designation is stated on the rating plate of most motor types.

If the bearing in the D-end of the motor is replaced with roller bearings NU- or NJ-, higher radial forces can be handled. Roller bearings are especially suitable for belt-driven applications.

With high axial forces, angular contact ball bearings should be used. This type of bearing is usually needed when motors are mounted vertically. When ordering a motor with angular contact ball bearings, the method of mounting and direction and magnitude of axial force must be specified.

Single angular contact bearings are not suitable for horizontally mounted motors where low axial forces are possible. Double angular contact ball bearings arranged back to back or face to face are recommended in case there are low axial forces in a horizontally mounted motor, or if the direction of the axial force can change. See the product catalog of the motor in question for more specific information about bearings.

Bearing life

The normal bearing life L10h of a bearing is defined, according to ISO 281, as the number of operating hours achieved or exceeded by 90 % of identical bearings in a large test series under specific conditions. 50 % of bearings achieve at least five times this lifetime.

The nominal bearing life is the lifetime that 90 % of identical bearings achieve or exceed before first signs of material weariness appear.
A sufficient grease layer inside the bearing and usage in a correct application are preconditions for a nominal bearing life. By definition, 10 % of bearings can fail before they reach the nominal bearing life. Consequently, bearing life should never be confused with warranty period.

The usual values for bearing lifetime of standard motors are 40,000 h for belt drive and 100,000 h for direct coupling.

—
Figure 5.7
Bearing arrangements in Process performance cast iron motors, sizes 280 to 450

Bearing size

Reliability is the main criteria for bearing size design, taking into account the most common types of application, load of the motor and motor size. ABB uses series 63 bearings which are of robust design for longer life and higher loadability. 62 series bearings have lower noise levels, higher maximum speeds, and lower losses. See product catalogs and motor rating plates for exact bearing types.

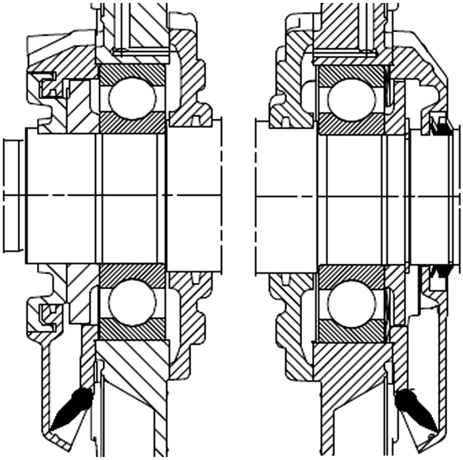

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Figure 5.7

5.5 Drain holes and humidity

Absolute humidity is the amount of water (g/m3) in a certain volume of air. Its value, so-called saturation value, increases when temperature increases. Relative humidity is the ratio between absolute air humidity and saturation value at a certain ambient temperature. When air cools below the temperature where the dew point is reached (relative humidity is 100 %), condensation on cold surfaces takes place.

Humidity is a risk not only to the external surface of the motor; it may also lead to internal corrosion.

When totally enclosed machines heat up, the air inside them expands; when they cool down the air volume decreases. The volume increase and decrease depend on the temperature difference to the ambient air. When the motor cools down, it may suck in particles and humidity that could damage bearings and insulation. The advantage of the drain holes is that they prevent ventilation through bearings and terminal box. Drain holes can be opened and closed with plastic plugs.

When temperature difference to ambient air is high, heating elements fitted to the winding heads may be needed to prevent corrosion of the windings. If humidity inside the motor is suspected, special measures such as insulation resistance measurement or drying in an oven need to be taken to avoid permanent damage to the motor.

5.6 External radial and axial forces of the motor

Depending on the purpose of use, and in addition to the rotational torque which is always present when running the motor, the shaft end may be affected by external radial or axial forces. Radial forces are those that are perpendicular to the shaft, while axial forces are linear with the shaft. The shaft end may also be exerted by both radial and axial forces at the same time. The maximum radial and axial forces are given in product catalogs per each motor type in Newtons. In case of radial forces, it is essential to know the exact position of the load on the shaft extension. If the shaft extension will be affected simultaneously by both radial and axial forces, the load capacity of the motor needs to be checked case by case with ABB.

5.7 Balancing

The rotor is dynamically balanced in the keyway of the shaft extension with a half-sized key (half-key balancing) according to standard ISO 8821. Balancing with a full key or without a key are also available on request. By default, ABB motors are balanced to grade G2.5 according to ISO 1940/1. Balancing to grade G1 is available on request. When the motor is ordered with higher vibration class B (see Vibration), the rotor balancing grade is G1 by default.

There are two possibilities for checking balancing quality afterwards: removing the rotor out of the motor and placing it on a balancing machine, or checking it by a vibration measurement tool. The latter can be done as follows: Lift the motor with a lifting lug and leave it hanging, or place it standing on soft rubber, for example. Run the motor at nominal speed and check vibration level. The measured vibration level should be less than 1.5 mm/s (rms) for a new motor.

5.8 Vibration

Effective values (root mean squares, rms) of vibration velocity are defined in the IEC 60034-14 standard (see Table 5.1). Requirements apply across the measuring range of 10 to 1000 Hz. The purpose of this standard is to measure the vibration behavior of a machine alone at no load, under defined conditions in a reproducible and comparable way, the motor placed on elastic mounting. However, though vibration severity depends on the balancing grade used, it also essentially depends on the properties of coupling to the driven machine and coupling parts used.

Possible origins of severe vibration of coupled motors can be incorrect balancing (half key/full key), inaccurate alignment of the motor with a coupled machine, and resonance of the system (motor and foundation). ABB motors fulfill grade A vibration level by default.

Vibration is expressed in mm/s RMS.

Table 5.1 Limits of maximum vibration magnitude in displacement, velocity and acceleration (rms) for shaft height H

	Shaft height, mm	**56 ≤ H ≤ 132**			**132 < H ≤ 280**			**H > 280**		
Vibration grade	**mounting**	Displac. µm	Vel. mm/s	Acc. m/s^2	Displac. µm	Vel. mm/s	Acc. m/s^2	Displac. µm	Vel. mm/s	Acc. m/s^2
A	Rigid mounting	25	1.6	2.5	35	2.2	3.5	45	2.8	4.4
	Free suspension	21	1.3	2.0	29	1.8	2.8	37	2.3	3.6
B	Free suspension	11	0.7	1.1	18	1.1	1.7	29	1.8	2.8
	Rigid mounting		-		14	0.9	1.4	24	1.5	2.4

Table 5.1

Table 5.2
Atmospheric corrosivity categories and recommended environment

5.9 Surface treatment

The surface treatment categorization of ABB motors is based on the ISO 12944 standard. ISO 12994-5 divides paint system durability into three categories: low (L), medium (M), and high (H). Low durability corresponds to a lifetime of 2 – 5 years, medium to 5 – 15 years, and high durability to over 15 years.

The durability range is not a guaranteed lifetime. Its purpose is to help the owner of the motor plan for appropriate maintenance intervals. More frequent maintenance may be required because of fading, chalking, contamination, wear and tear, or for other reasons.

ABB’s standard surface treatment is corrosivity category C3, durability range M (which corresponds to medium corrosivity and medium durability). Special surface treatment is available in corrosivity categories.

C4 and C5-M, durability class M for both. See table below for more details. In addition, surface treatment according to the NORSOK standard for offshore environments is available as an option.

The standard ABB paint color for motors is Munsell blue 8B 4.5/3.25.

Corrosivity category	Outdoor atmospheres	Indoor atmospheres	Use in ABB motors
C1, very low	Not used	Heated buildings with clean atmospheres	Not available
C2, low	Atmospheres with low level pollution, mostly rural areas.	Unheated buildings where condensation may occur, such as depots and sports halls.	Not available
C3, medium	Urban and industrial atmospheres, moderate sulfur dioxide pollution. Coastal areas with low salinity.	Production rooms with high humidity and some air pollution; food processing plants, laundries, breweries, dairies.	Standard treatment
C4, high	Industrial areas and coastal areas with moderate salinity.	Chemical plants, swimming pools, coastal ship- and boatyards.	Optional treatment, variant code 115
C5-I, very high (industrial)	Industrial areas and coastal areas with high humidity and aggressive atmosphere.	Buildings or areas with nearly permanent condensation and high pollution.	Not available
C5 -M, very high (marine)	Coastal and offshore areas with high salinity.	Buildings or areas with nearly permanent condensation and high pollution.	Optional treatment, variant code 754

Table 5.2

Noise

Noise is subject to strict regulations today, with maximum permitted levels. Accordingly, ABB considers noise reduction a major design criterion in the development of our motors.

Noise

Figure 6.1
Human hearing range

6.1 Sound pressure level and sound power level

Sound is pressure waves sent out by a source through the medium (usually air) in which it is immersed. Sound pressure is measured in decibels (dB) during a noise test. The ratio between the threshold of hearing and the threshold of pain is 1:10 000 000. As the pressure scale is so large and since we experience a 10 dB difference as a doubling of the perceived sound level, a logarithmic scale is employed where:

Sound pressure level $L_p = 10 \log [(p/p_0)^2]$ [dB]

$p_0 = 20\ \mu\text{Pa}$ is the threshold of hearing for an average person

p = measured pressure [Pa]

Sound pressure is measured in a test room to eliminate the effect of reflected noise and external sources. A microphone is placed at various positions around the motor in order to measure sound radiation into different directions. Usually the distance of the microphone from the motor surface is one meter. As the noise level varies in different directions due to the influence of internal sources, a tolerance of 3 dB is applicable for the average sound pressure level. Information on sound pressure level is meaningful only if the distance from the sound source is stated. For example, Lp = 80 dB at a distance of one meter from a point sound source corresponds to 70 dB at three meters.

The measured sound level Lp can be converted into power radiated from the sound source, to determine the sound power level Lw. The formula for this is:
Lw = Lp + Ls (Ls is calculated from the area of the measurement surface, according to ISO). Thus, sound power level is usually a larger number than the corresponding sound pressure level. Care should be taken not to confuse the quantities.

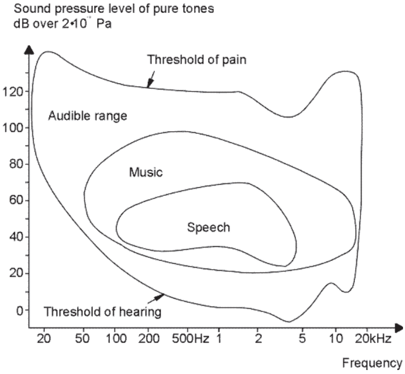

Figure 6.1

—
Figure 6.2 Filter characteristics for A-weighting

The use of sound power instead of sound pressure to describe noise emission from a motor is encouraged: because sound pressure is a function of distance and environmental factors (reflections), sound power is fixed. There is an analogy to heating radiator: If you use a 1000 W electrical heater to warm up a room, the final temperature of the room depends on the insulation of the walls, room size etc. Here the temperature is analog to sound pressure.

6.2 Weighting filters

Amplifiers and various filters are used when measuring composite sound. Normally only the LpA figure is given. It corresponds best with the perception of the ear.

Filters let through an entire frequency range, but attenuate or amplify certain parts of it. The resulting frequency curves resemble stylized 40-, 70- and 100-phon curves for pure tones.

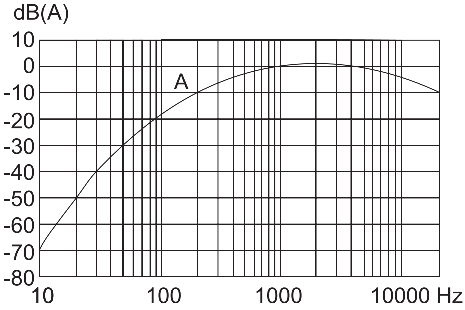

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Figure 6.2

Figure 6.3
Noise rating
(NR) curves

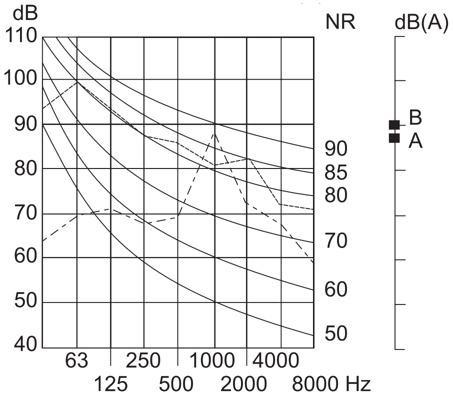
6.3 Octave bands

Mean sound pressure level is measured with a broad band filter covering the entire frequency band. Measurement is also done with a narrow band filter to define noise level per octave band (frequency band), as the perception of the human ear is dependent on the octave band.

Octave band analysis
To get an idea of the character of composite sound, it has proven practical to divide the frequency range into octave bands with a ratio of 1:2 between the band limit frequencies. The frequency range is usually referred to by the mid-frequency of the band. The measured dB figures for all octave bands are generally shown in the form of an octave band diagram.

A system of noise rating curves known as NR curves has been developed under ISO to express the subjective degree of disturbance from different noises. These curves are intended to be used when assessing the risk of damage to hearing. Similar systems are also available. NR curve numbers signify the degree of noise.

For the octave band with a mid-frequency of 1,000 Hz, the number is equal to the sound pressure level in dB. The NR curve that touches the noise curve of the motor in question determines the motor's noise rating. The table below illustrates the use of noise rating. It shows how long a person can remain in a noisy environment without getting permanent hearing damage.



A ––– No risk of hearing damage. The NR 85 curve touches the noise curve of the motor. The noise level is 88 dB(A).

B ---- Risk of hearing damage. The NR 88 curve touches the noise curve of the motor. The noise level is 90 dB(A).

NR	**Time per day**
85	> 5 hours
90	= 5 hours
95	= 2 hours
105	< 20 minutes
120	< 5 minutes

Figure 6.3

Figure 6.4
Effect of sound sources on total sound pressure level

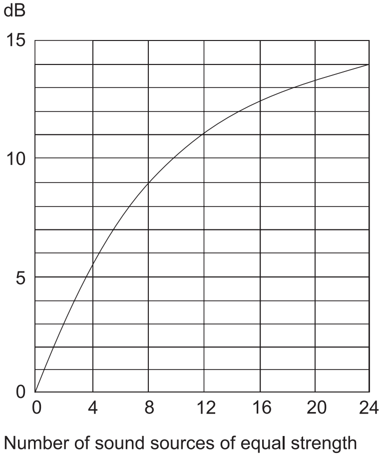
6.4 Additional sound sources

Perception of difference in sound level
A difference of 1 dB in sound level is barely detectable, whereas a 10 dB difference is perceived as doubling or halving of the sound level.

The diagrams below illustrate the total sound pressure level when several sound sources are present. For example, diagram A shows that the sound pressure level will be 3 dB higher if the sound levels of two identical sources are added together. Diagram B shows how the sound level pressure changes when the sound sources have different pressure levels.

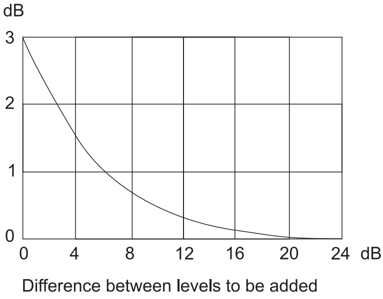
However, before logarithmic values can be added or subtracted, they must be converted into absolute numbers. An easier way of adding or subtracting sound sources is to use the diagrams below.

Increase in total sound pressure level



Adding several equal sound sources. Adding together two such sources increases the total level by 3 dB; adding together four increases it by 6 dB, and so on.

Increase in total sound pressure level



Adding two different levels. When the difference between the two sound pressure levels is greater than 10 dB, the lower level contributes so little to the total sound pressure level it may be disregarded.

Figure 6.4

6.5 Noise components of a motor

The total sound power emission from a motor can be considered a combination of three uncorrelated noise sources acting together. These sources are magnetic, cooling, and mechanical or rotational noise sources. Magnetic noise results from temporal and spatial variations of magnetic force distribution in the air gap. Operating a cooling fan creates most of the cooling noise. Rotational noise is generated when 1) an unsmooth body (rotor) rotates in a cavity that has obstacles and discontinuities, and 2) the shaft and the bearings interact. The magnitude of each source depends on motor type. The major factors affecting each of the sources in a motor are:

Magnetic noise P_{magn} [W]
- shaft load
- voltage, current, frequency, and supply type
- winding parameters
- slot geometry
- saturation, eccentricity, etc.

Cooling noise P_{cool} [W]
- fan type: axial, radial, or mixed flow
- rotational speed and fan diameter
- airflow velocity
- cooling method; closed vs. open, water vs. air

Mechanical or rotational noise P_{rot} [W]
- type of cooling: closed or open
- type of bearings
- speed

The total sound power level L_{Wtot} of an electrical machine in decibels can be expressed as

$$L_{Wtot} = 10 \log_{10} \left(\frac{P_{magn} + P_{cool} + P_{rot}}{P_{ref}} \right)$$

Here P_{ref} = 1 pW is the reference sound power. The equation shows that the total sound power level of an electrical machine is the result of all of the sources.

The equation is useful in considering the reduction of the total sound power of an electrical machine. Reduction measures should first be applied to the most dominant source. The following examples clarify this concept:

- For a 2-pole directly-cooled motor, the cooling noise produces 99 % of the total sound power, which means that neither the loading nor the converter supply will increase the total sound power level of the machine.

- For an 8-pole totally-closed machine with water cooling, magnetic noise dominates the total noise output and thus the loading and/or the converter supply will increase the sound power level to some extent.

- With sinusoidal supply, loading the machine can increase the magnetic sound output significantly, but with frequency converter supply, the increase of the noise output is usually much smaller.

- Cooling noise can be reduced by optimized fan design. Similarly, increasing the overall efficiency of the motor means that fan diameter can be reduced. However, the fan must be large enough to generate sufficient air flow so that adequate cooling of the motor is ensured.

- The noise level of larger motors can be reduced by fitting a silencer. On larger 2-pole motors, a unidirectional fan which rotates in one direction only and so generates less noise can be used.

- At fixed PWM converter duty, the motor noise produced in certain octave bands can change considerably depending on the switching frequency of the converter. The converter does not produce sinusoidal voltage. However, as ABB Direct Torque Control converters do not have a fixed switching frequency, the noise level is lower than would be the case if a fixed switching frequency converter was used with the same motor.

Table 6.1 Sound pressure levels for aluminum motors

Table 6.2 Sound pressure levels for cast iron motors

6.6 Sound pressure levels

The following two tables present sound pressure levels for Process performance motors in a 400 V network, at 50 Hz net duty. We still use sound pressure to describe noise levels in low voltage motors, because much of reference data uses the same quantity.

To roughly convert sound pressure level into sound power, simply add the reference value in the last column to the given sound pressure value. Both quantities are indicated in decibel. The given conversion values are only approximate and will vary also according to motor length and type.

Frame size	2 poles dB(A)	4 poles dB(A)	6 poles dB(A)	8 poles dB(A)	Add to get sound power
63	54	40	38	32	5
71	58	45	42	43	6
80	60	50	47	50	6
90	63	50	44	52	7
100	62	63	49	53	7
112	68	64	56	55	8
132	73	66	61	58	8
160	69	65	59	59	9
180	69	62	59	59	9
200	72	63	63	68	10
225	74	66	63	60	10
250	75	67	63	63	11
280	75	67	63	63	11

Table 6.1

Frame size	2 poles dB(A)	4 poles dB(A)	6 poles dB(A)	8 poles dB(A)	Add to get sound power
71	58	45	42	43	6
80	60	50	47	50	6
90	69	56	44	53	7
100	68	58	49	53	7
112	70	59	66	55	8
132	70	67	57	58	8
160	69	62	59	59	9
180	69	62	59	59	9
200	72	63	63	60	10
225	74	66	63	63	10
250	75	67	66	65	11
280	77	75	70	72	12
315	78	78	70	72	13
355	83	78	75	75	14
400	82	78	77	71	15
450	85	85	81	80	15

Table 6.2

Installation and maintenance

Each motor must be installed and maintained in accordance with the manual included in the delivery of the motor. The installation and maintenance instructions in this chapter are a generic guideline.

Installation and maintenance

7.1 Delivery acceptance

1. When delivered, inspect the equipment for transit damages. If any damages are found, inform the forwarding agent immediately.

2. Check data on the rating plate. Pay special attention to voltage and winding connection (star or delta).

3. Remove transit locking if fitted, and turn shaft by hand to verify that it rotates freely.

7.2 Insulation resistance check

Before commissioning the motor, or when winding dampness is suspected, insulation resistance measurement is required.

Resistance, corrected to 25 °C, must exceed the reference value, 10 MΩ (measured with 500 V or 1000 V DC). The insulation resistance is halved for each 20°C rise in winding temperature.

WARNING: *The motor frame must be grounded and windings discharged against the frame immediately after measurement to avoid the risk of electric shock.*

If the reference resistance value is not attained, the winding is too damp and must be oven-dried at 90 °C for 12 - 16 hours, followed by 105 °C for 6 - 8 hours. Drain hole plugs, if fitted, must always be removed before oven-drying, and closing valves, if fitted, must be opened.

Windings drenched in seawater normally need to be rewound.

Table 7.1
Tightening torques for steel screws and nuts

7.3 Torque on terminals

The following torque table is a generic guideline for tightening torques. The motor's frame material and surface treatment must be taken into account when determining the tightening torque.

Thread	4.60 Nm	6.8 Nm	8.8 Nm	10.9 Nm	12.9 Nm
M2.5	0.24	-	-	-	-
M3	0.42	-	-	-	-
M5	2	4	5	8	9
M6	3	7	9	13	15
M8	8	16	21	33	37
M10	16	32	43	63	73
M12	27	55	73	108	126
M14	44	88	117	172	200
M16	67	134	180	264	309
M20	130	262	363	517	605
M22	176	353	495	704	824
M24	226	450	625	890	1040
M27	330	660	915	1300	1530
M30	450	900	1250	1780	2080
M33	610	-	-	-	-
M36	780	-	-	-	-

Table 7.1

7.4 Operation

Operating conditions
LV motors are designed for use in industrial applications under the following conditions.

- Normal ambient temperature range from - 20 °C to + 40 °C
- Maximum altitude 1,000 m above sea level
- Tolerance for supply voltage is ±5 % and for frequency ±2 % according to EN/IEC 600034-1.

Safety
All motors must be installed and operated by qualified personnel familiar with the relevant health and safety requirements and national legislation. Safety equipment necessary for the prevention of accidents at the installation and operation site must be provided in accordance with local requirements.

WARNING
Small motors with supply current directly switched by thermally sensitive switches can start automatically.

Accident prevention
Special instructions may also apply to certain motor applications such as frequency converter supply.

7.5 Handling

Storage

- Motors should always be stored in a dry, vibration-free and dust-free environment.
- Unprotected machined surfaces (shaft-ends and flanges) should be treated with an anti-corrosive.
- It is recommended that shafts are periodically rotated by hand to prevent grease migration.
- Anti-condensation heaters are recommended to avoid water condensation in the motor and should preferably be energized.
- The characteristics of electrolytic capacitors, if fitted to single-phase motors, will require “reforming” if stored over 12 months.

Transportation
Motors fitted with cylindrical-roller and/or angular-contact bearings must be secured with locking devices during transport.

Motor weight
The total weight and the center of gravity of motors with the same frame size can vary because of different output, mounting arrangements and auxiliary equipment. The actual weight of the motor is marked on the rating plate.

7.6 Foundations

The end user of the motor has full responsibility for preparation of the foundation for the motor.

The foundation must be smooth, level and, if possible, vibration free. A concrete foundation is therefore recommended. If a metal foundation is used, it should be treated with an anti-corrosive.

The foundation must be stable enough to withstand possible short-circuit forces. Short-circuit torque is primarily a damped sinusoidal oscillation and can thus have both positive and negative values. Stress on the foundation can be calculated with the help of data tables in the motor's catalog and the formula below.

$$F = 0.5 \times g \times m + \frac{4 \times T_{max}}{A}$$

Where F = stress per side, N
g = gravitational acceleration, 9.81 m/s^2
m = motor weight, kg
T_{max} = maximum torque, Nm
A = lateral distance between the holes in the motor's feet, m.

Dimension A is given in the motor's dimension drawing in millimeters.

The foundation should be dimensioned to afford a sufficiently large resonance gap between the natural frequency of the installation and various interference frequencies.

Foundation studs

The motor should be secured with foundation studs or a base plate. Motors for belt drives should be mounted on slide rails.

The foundation studs are bolted to the feet of the motor once locating pins have been inserted in the holes reamed for the purpose. The studs must be fitted to the correct feet with a 1 - 2 mm shim between the stud and the feet; see the markings on the studs and on the stator feet. Place the motor on the foundation and align the coupling. Use a spirit or laser level to verify that the shaft is horizontal. The height of the stator frame can be adjusted by setting either screws or shims. When you are sure the alignment is correct, grout the blocks.

7.7 Coupling alignment

Motors must always be aligned accurately. This is particularly important in the case of directly coupled motors. Incorrect alignment can lead to bearing failure, vibration, and even shaft fracture. In the event of bearing failure or if vibration is detected, the alignment should be checked immediately.

The best way of achieving proper alignment is to mount a pair of dial gauges as shown (page 100). Each gauge is on a coupling half, and they indicate the difference between the coupling halves both axially and radially. Slowly rotating the shafts while observing the gauge readings gives an indication of the adjustment that need to be made. The coupling halves must be loosely bolted together so that they can easily follow each other when turned.

To determine whether the shafts are parallel, measure with a feeler gauge the distance between the outer edges of the coupling halves at a point on the periphery: see Figure 7.2. Then turn both halves together through 90° without changing the relative positions of the shafts, and measure again at exactly the same point. Measure the distance again after rotating 180° and 270°. For typical coupling sizes, the difference between the highest and lowest readings must not exceed 0.05 mm.

To check that the shaft centers are directly opposite each other, place a steel ruler parallel with the shafts on the turned periphery of one coupling half and then measure the clearance between the periphery of the other half and the ruler in four positions as a parallelism check. The difference between the highest and lowest readings must not exceed 0.05 mm.

When aligning a motor with a machine whose frame reaches another temperature than the motor itself in normal service, allowance must be made for the difference in shaft height resulting from different thermal expansion. For the motor, the increase in height is about 0.03 % from ambient temperature to operating temperature at full output. Mounting instructions from manufacturers of pumps, gear units etc. often state the vertical and lateral displacement of the shaft at operating temperature. Bear in mind the effects of thermal expansion to avoid vibration and other problems in service.

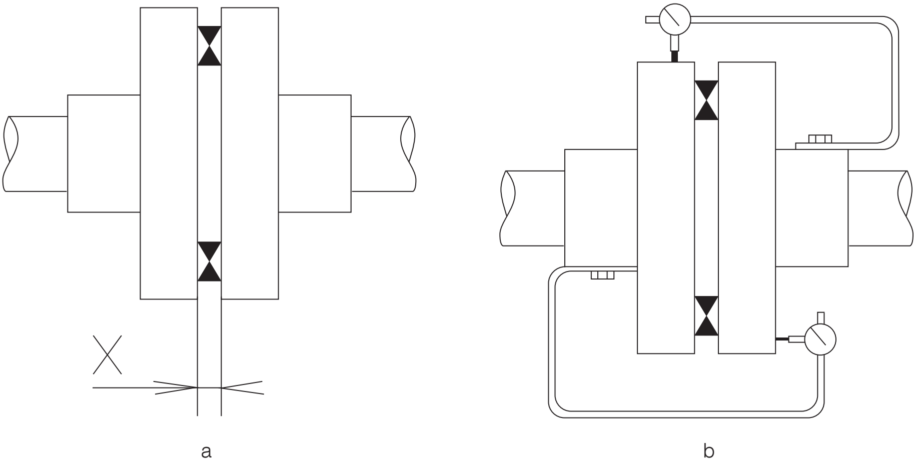


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Figure 7.2

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Figure 7.2
Angular
deviation
and motor
alignment

7.7.1 Mounting pulleys and coupling halves

Care must be taken when fitting pulleys and coupling halves to prevent damage to bearings. They must never be forced in place or levered out. The pulleys and coupling halves with interference fit are heated before installation. The heating of the pulley or coupling half can be done with an induction heater or a gas torch, or in an oven.

A coupling half or pulley with a sliding fit can be pushed onto the shaft by hand for about half the length of the shaft extension. A special tool or fully-threaded bolt, a nut and two flat pieces of metal are then used to push the coupling half or pulley fully home against the shoulder of the shaft.

Figure 7.3
Attaching
slide rails

7.8 Slide rails

Motors for belt drives should be mounted on slide rails as shown in Figure 7.3. Place slide rails horizontally on the same level. Then position the motor and slide rails on the foundation and align them so that the middle of the motor pulley coincides with the middle of the pulley on the driven machine. Check that the motor shaft is in parallel with the drive shaft, and tension the belt in accordance with supplier instructions. Do not exceed the maximum belt forces (radial bearing loads) stated in the product catalog. The slide rail nearest the belt must be positioned so that the tensioning screw is between the motor and driven machine. The screw on the other slide rail must be on the other side. After alignment, grout in the slide rail fixing bolts.

WARNING
Do not over-tension the belts. Excessive belt tension can damage bearings and cause shaft fracture.

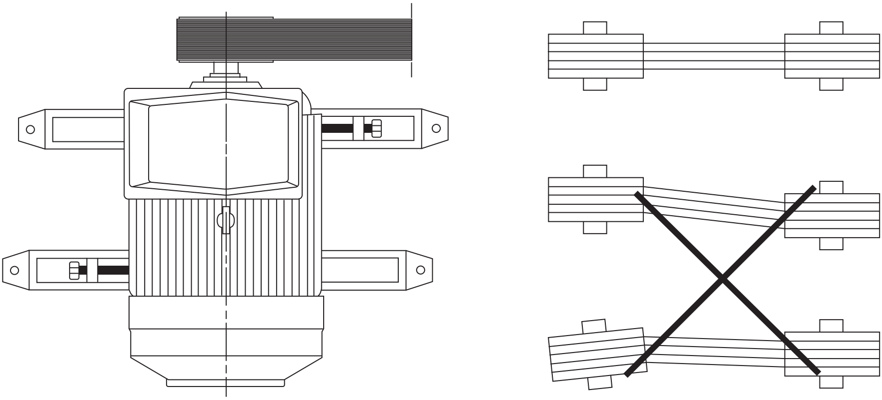


Figure 7.3

7.9 Mounting bearings

Always take special care with bearings. Bearings should be fitted by heating or with purpose-made tools and removed with pullers. The maximum heating temperature is 100 °C. Detailed information can be obtained from the bearing supplier.

When a bearing is mounted on the motor shaft, cold or hot mounting may be used. Cold mounting is only suitable for small bearings and bearings that do not have to be pressed far onto the shaft. For hot mounting and where the bearing is shrink-fitted on the shaft, the bearing is first heated in an oil bath or with a special heater. It is then pressed onto the shaft with a mounting sleeve that fits the inner ring of the bearing. Grease-filled bearings, which usually have sealing plates or shield plates, should not be heated.

7.10 Lubrication

Reliability is a key driver in bearing design and in bearing lubrication systems. That is why ABB, as standard, follows the L_1-principle: 99 per cent of motors will make the interval time). The lubrication intervals can also be calculated according to the L_{10} principle, which means that 90 per cent of motors will make the interval time. L_{10}-values, which are normally doubled compared to L_1-values, are available from ABB at request.

Motors with permanently greased bearings
Motors up to frame size 250 are normally fitted with permanently greased bearings of type Z or 2Z. Process performance motors are normally provided with grease nipples.

Guidelines for bearing lifetime
- 4-pole motors: 20,000 – 40,000 duty hours[1)]
- 2 and 2/4-pole motors: 10,000 – 20,000 duty hours[1)]
- Shorter intervals apply to larger motors.

[1)] Depending on the application and load conditions

Motors with a lubrication system
Lubricate the motor when operational. If a grease outlet plug is fitted, remove it temporarily when lubricating, or remove permanently with auto-lubrication. If the motor is fitted with a lubrication plate, use the values shown on the plate; otherwise lubricate according to the L_1 -principle.

Table 7.2 Fuse rating table

7.11 Fuse rating

The following table is a guideline for selecting a fuse and a switch-fuse for a motor connected direct on line in a 400 V, 50 Hz network.

P	**I_N (A) per motor's rotation speed**					
kW	**750**	**1000**	**1500**	**3000**	**Switchfuse**	**Standard fuse**
0.09	0.53	-	-	-	OS 32 D12	2aM
0.12	0.63	0.59	-	-	OS 32 D12	2aM
0.18	0.90	0.75	0.72	-	OS 32 D12	2aM
0.25	1.18	0.92	0.83	0.70	OS 32 D12	2aM
0.37	1.6	1.25	1.12	0.93	OS 32 D12	2aM
0.55	2.4	1.78	1.45	1.33	OS 32 D12	2aM
0.75	2.7	2.4	1.9	1.7	OS 32 D12	4aM
1.1	3.35	3.3	2.55	2.4	OS 32 D12	4aM
1.5	4.5	4.1	3.4	3.3	OS 32 D12	6aM
2.2	5.9	5.4	4.8	4.5	OS 32 D12	10aM
3.0	7.8	6.9	6.5	6.0	OS 32 D12	10aM
4.0	10.0	8.7	8.6	7.4	OS 32 D12	16aM
5.5	13.4	11.9	11.1	10.5	OS 32 D12	16aM
7.5	18.1	15.4	14.8	13.9	OS 32 D12	20aM
11	25	23	22	20	OS 32 D12	32aM
15	29	31	29	27	OS 63 D12	40aM
18.5	36	36	37	33	OS 63 D12	50aM
22	45	43	42	40	OS 63 D12	63aM
30	60	59	56	53	OS 125 D12	80aM
37	74	69	68	64	OS 125 D12	100aM
45	90	82	83	79	OS 125 D12	125aM
55	104	101	98	95	OS 250 D03P	160aM
75	140	140	135	131	OS 250 D03P	200aM
90	167	163	158	152	OS 250 D03P	200aM
110	202	199	193	194	OS 400 D03P	250aM
132	250	238	232	228	OS 400 D03P	315aM
160	305	280	282	269	OS 630 D03P	355aM
200	395	355	349	334	OS 630 D03P	500aM
250	470	450	430	410	OS 630 D03P	630aM
315	605	565	545	510	OS 800 D03P	800aM
355	680	635	610	580	OS 800 D03P	800aM

Table 7.2

The SI system

This section explains some of the units in the International System of Units (SI) that are used in conjunction with electric motors and their application.

A distinction is made between quantity, quantity value, unit, measurement number and between the name and symbol of a unit. These distinctions are explained in the following example.

Example: P = 5.4 W, i.e. the power is 5.4 watts, where:

Quantity name = power
Quantity symbol = P
Quantity value = 5.4 watts
Unit name = watt
Unit symbol = W
Numerical value = 5.4

The SI system

8.1 Quantities and units

Quantity Name	Symbol	Unit Name	Symbol	Remarks
Space and time				
Plane angle	α β γ	Radian	rad	
		Degree	...°	1° = π/180 rad
		Minute	...’	
		Second	...”	
Length	l	Meter	m	
Area	A	Square meter	m^2	
Volume	V	Cubic meter	m^3	
		Litre	l	
Time	t	Second	s	
		Minute	min	
		Hour	h	
Frequency	f	Hertz	Hz	
Velocity	v	Meter per second	m/s	km/h is the commonest multiple
Acceleration	a	Meter per second squared	m/s^2	
Free fall acceleration	g	Meter per second squared	m/s^2	
Energy				
Active	W	Joule	J	1 J = 1 Ws = 1 Nm
Watt second	Ws			
Watt hour	Wh			
Reactive	Wq	Var second	vars	
		Var hour	varh	
Apparent	Ws	Volt-ampere second	VAs	
		Volt-ampere hour	VAh	
Power				
Active	P	Watt	W	1 kW = 1.34hp[1] = 102 kpm/s = s = 10^3 Nm/s = 10^3 J/s
Reactive	Q, Pq	Var	var	
Apparent	S, Ps	Volt-ampere	VA	

[1] kW = 1.34 hp (UK, US) is used in IEC Publ 72
1 kW = 1.36 hp (metric horsepower)

Quantity Name	Symbol	Unit Name	Symbol	Remarks
Mechanical				
Mass	m	Kilogram	kg	
		Tonne	t	1° = π/180 rad
Density	ρ	Kilogram per cubic meter	kg/m^3	
Force	F	Newton	N	1 N = 0.105 kp
Moment of force	M	Newton-meter	Nm	1 Nm = 0.105 kpm = 1 Ws
Moment of inertia	J	Kilogram-meter	kgm^2	J = G x D2
Pressure	p	Pascal	Pa	1 Pa = 1 N/m^2
		Newton per square meter	N/m^2	1 N/m^2 = 0.102 kp/m^2 = 10-5 bar
		Bar	bar	1 bar = 105 N/m^2
Heat				
Thermodynamic temperature	T, θ	Kelvin	K	Old name: absolute temperature
Celsius temperature	ϑ, t	Degree Celsius	°C	0 °C = 273.15 K
Temperature	ΔT, Δϑ	Kelvin	K	The interval 1 K is identical to difference the interval 1 °C
		Degree Celsius	°C	
Thermal energy	Q	Joule	J	
Electricity				
Electric potential	V	Volt	V	1 V = 1 W/A
Electric voltage	U	Volt	V	
Electric current	I	Ampere	A	
Capacitance	C	Farad	F	1 F = 1 C/V
Reactance	X	Ohm	Ω	
Resistance	R	Ohm	Ω	1 Ω = 1 V/A
Impedance	Z	Ohm	Ω	$Z = \sqrt{R^2+X^2}$

8.2 Prefixes

Multiples of SI units are indicated by the following prefixes. The use of prefixes in brackets should be avoided because they not generally well-known.

10^3	kilo	k	10^{-6}	micro	µ
(10^2)	(hecto)	(h)	10^{-9}	nano	n
(10^1)	(deca)	(da)	10^{-12}	pico	p
(10^{-1})	(deci)	(d)	10^{-15}	femto	f
(10^{-2})	(centi)	(c)	10^{-18}	atto	a
10^{-3}	milli	m			

8.3 Conversion factors

The units generally used for technical applications are SI units.

However, other units may be encountered in descriptions, drawings, etc., especially where the inch system is involved.

Note that the US gallon and the UK gallon are not the same. To avoid confusion it is advisable to use the abbreviation ‘US’ or ‘UK’ after the unit. The following table lists some of most commonly needed conversion factors.

Length	
1 nm = 1.852 km	1 km = 0.540 nm
1 mile = 1.609344 km	1 km = 0.621 mile
1 yd = 0.9144 m	1 m = 1.09 yd
1 ft = 0.3048 m	1 m = 3.28 ft
1 in = 25.4 mm	1 mm = 0.039 in
Velocity	
1 knot = 1.852 km/h	1 km/h = 0.540 knot
1 m/s = 3.6 km/h	1 km/h = 0.278 m/s
1 mile/h = 1.61 km/h	1 km/h = 0.622 mile/h
Area	
1 acre = 0.405 ha	1 ha = 2.471 acre
1 ft^2 = 0.0929 m^2	1 m^2 = 10.8 ft^2
1 in^2 = 6.45 cm^2	1 cm^2 = 0.155 in^2
Volume	
1ft^3 = 0.0283 m^3	1 m^3 = 36.3 ft^3
1 in^3 = 16.4 cm^3	1 cm^3 = 0.0610 in^3
1 gallon (UK) = 4.55 l	1 l = 0.220 gallon (UK)
1 gallon (US) =3.79 l	1 l = 0.264 gallon (US)
1 pint = 0.568 l	1 l = 1.76 pint
Flow	
1 m^3/h = 0.278 x 10-3 m^3/s	1 m^3/s = 3600 m^3/h
1 cfm = 0.472 x 10-3 m^3/s	1 m^3/s = 2120 cfm
Mass	
1 lb = 0.454 kg	1 kg = 2.20 lb
1 oz = 28.3 g	1 g = 0.0352 oz
Force	
1 kp = 9.80665 N	1 N = 0.105 kp
1 lbf = 4.45 N	1 N = 0.225 lbf
Pressure	
1 mm vp = 9.81 Pa	1 Pa = 0.102 mm vp
1 kp/cm^2 = 98.0665 kPa	1 kPa = 0.0102 kp/cm^2
1 kp/cm^2 = 0.980665 bar	1 bar = 1.02 kp/m^2
1 atm = 101.325 kPa	1 kPa = 0.00987 atm
1 lbf/in^2 = 6.89 kPa	1 kPa = 0.145 lbf/in^2

Energy	
1 kpm = 9.80665 J	1 J = 0.102 kpm
1 cal = 4.1868 J	1 J = 0.239 cal
1 kWh = 3.6 MJ	1 MJ = 0.278 kWh
Power	
1 hp = 0.736 kW	1 kW = 1.36 hp
1 hp (UK, US) = 0.746 kW	1 kW = 1.34 hp (UK, US)
1 kcal/h = 1.16 W	1 W = 0.860 kcal/h
Temperature	
0 °C	= 32 °F
°C	= 5/9 (°F - 32)
0 °F	= -17.8 °C
°F	= 9/5 (°C + 32)

Comparison table for temperatures

°F	**°C**
0	-17.8
10	-12.2
20	-6.7
30	-1.1
32	0
40	4.4
50	9.9
60	15.5
70	21.0
80	23.6
90	32.1
100	37.8

NEMA vs. IEC frame sizes

NEMA			**IEC**		
Frame	Shaft height (in)	Shaft height (mm)	Frame	Shaft height (in)	Shaft height (mm)
			63	2.48	63
42	2.625	66.675	71	2.795	71
48	3	76.2	80	3.15	80
56/140T	3.5	88.9	90	3.543	90
			100	3.937	100
180T	4.5	114.3	112	4.409	112
210T	5.3	133.35	132	5.197	132
250T	6.3	158.75	160	6.299	160
280T		177.8	180	7.087	180
320T	8	203.2	200	7.874	200
360T	9	228.6	225	8.858	225
400T	10	254	250	9.843	250
440T	11	279.4	280	11.024	280
5000	12.5	317.5	315	12.402	315
5800	14.5	368.3	355	13.976	355
			400	15.748	400

Ordering

ABB's sales force plays a key role in defining the right product with the customer and communicating the customer order towards production units. The order specifications are initially defined at the offering phase, but will often be more accurate, or even changed, when placing the actual order. For the production units to deliver motors according to the customers' specifications and needs, it is important that all information stated in the order is correct, and no relevant information is missing.

This chapter explains how to select a motor and what tools there are to help in selection. Requirements for making a valid order are also introduced.

Ordering

9.1 Selecting a motor

There are three fundamental variables to consider when selecting a motor:

- electricity supply to which the motor will be connected
- type of enclosure or housing of the motor (IP class)
- starting method (see Electrical design)

Network voltage and frequency vary between regions and countries of the world. What is more, industries and applications may require voltages that are unrelated to the country where the motor is used or purchased, whereas frequency is usually region-specific. The table on the next page presents network voltages and frequencies in a number of selected countries and regions of the world. The voltages shown here are the most commonly available; be sure to verify the exact required voltage per each customer case.

Type of enclosure
There are two frame material options available: totally enclosed aluminum and cast- iron motor frames.

The totally enclosed fan-cooled (TEFC, which equals 'IP55 and IC411') motor is the predominant standard for industrial applications today. The versatile TEFC is a totally enclosed construction, with cooling air directed over the frame by a shaft-mounted fan.

On-line tools
On-line sales tools for selecting and dimensioning a motor are available on the web page https://new.abb.com/motors-generators/iec-low-voltage-motors.

Table 9.1.
World network voltages and frequencies

Area/country	Voltage V	Frequency Hz
Europe		
EU	220, 230, 400, 500, 690	50
Russia	220, 380	50
Africa		
Africa, majority of	220, 380, 400, 415	50
South Africa	220, 230, 380, 400, 500	50
Middle East		
Israel	220,230, 280, 400, 415	50
Saudi Arabia	220, 230, 380, 400, 440	50, 60
India	220, 230, 400, 415	50
North America		
Canada	230, 460, 575, 600	60
United States	230, 460, 480	60
Mexico	220, 480	60
Central America		
Cuba	220, 440	60
Costa Rica	240, 440	60
South America		
Brazil	220, 380, 440	60
Chile	220, 380, 400, 500	50, 60
Argentina	220, 380, 440	50
Northeast Asia		
China	380, 400	50
Japan	200, 220, 400, 440	50, 60
South Korea	220, 380, 440	60
Southeast Asia		
Philippines	115, 380, 440	60
Malaysia	240, 415	50
Indonesia	220, 380, 400	50
Oceania		
New Zeeland	230, 240, 400, 415	50
Australia	230, 240, 415, 440	50

Table 9.1.

9.2 Loading (kW)

Loading of the motor is determined by the equipment driven and the torque available on the shaft.

IEC electric motors have standard outputs per frame size. See Standards, Output power and frame size correlation for detailed information about how the standard determines power and frame size combinations.

Table 9.2.
Motor speeds

9.3 Speed

The induction motor is a fixed single-speed machine. Its speed depends on the frequency of the electricity supply and the stator winding design.

No-load speed is slightly lower than synchronous speed due to no-load losses in the machine. Full-load Further, full-load speed is typically 3 - 4 per cent lower than no-load speed.

Synchronous speed r/min = Frequency x 120 / number of poles

	50 Hz speed r/min	**60 Hz speed r/min**	
Number of poles	Synchronous	Synchronous	Typical full load
2	3000	3600	3450
4	1500	1800	1740
6	1000	1200	1150
8	750	900	850
10	600	720	700
12	500	600	580
16	375	450	430

Table 9.2.

9.4 Starting the motor

The available motor torque and load torque sometimes vary with rotation speed. The resulting accelerating torque in a certain moment of time depends on speed. The starting method is an important criterium in selecting a motor and must be carefully analyzed.

Between starting speed and nominal speed it must be ensured that even under unfavorable conditions (such as low voltage on motor terminals) the motor torque is always sufficiently high above the highest possible load torque. This has to be taken in account when selecting the starting method.

Further, in case of high starting frequency or heavy starting, overheating and its consequences must be taken into account.

9.5 Operating environment

The operating environment of the motor is another important factor to consider when ordering, because ambient temperature, humidity, and altitude can all affect performance.

Having an IP55 motor does not mean that it will remain tight in any outdoor operating conditions. The application where the motor is used, mounting position and actual exposure to external factors need to be taken into account. For example, ambient temperatures above 40 °C or altitudes above 1000 m mean reduced loadability. Similarly, mounting on the ceiling means that non-standard drain holes need to be ordered.

All metals corrode with varying intensity under the influence of chemicals and humidity. For example, pure aluminum and most of its alloys, without special surface treatment, are very sensitive to salt water. On the other hand, cast iron as such is durable against many chemicals except for the machined parts like drilling holes or centering borders. Selecting the right surface treatment will help lengthen the life of the motor and reduce the need for maintenance. See Mechanical Design, Surface treatment for further information.

9.6 Ordering and order check list

The following things must be known when placing a customer order:
- motor type, supply voltage and frequency, and product code
- mounting position
- variant codes for options in motor design or appliances, such as:
- cable flanges and other connection parts, unless standard
- special insulation and insulated bearings, unless standard
- duty type and ambient conditions
- rating values
- number of motors ordered
- price, delivery time, and delivery address
- quotation reference number

Order management system (OMS) is a complete order management and logistics system for low and high voltage motors, and it is used by ABB’s production units, It is often possible to deliver special features if they are based on the actual offer. If there is no variant code for a desired feature, you may check the availability, price and delivery time of the said feature through ABB sales personnel.

Variable speed drives

Squirrel cage induction motors offer excellent availability, reliability and efficiency. However, they have two weaknesses: high starting current and lack of smooth speed control over a wide speed range. A motor supplied by a variable speed drive (VSD) - also called frequency converter – usually solves both problems. A VSD-driven motor can be started softly with low starting current, and speed can be controlled and adjusted smoothly according to the application over a wide speed range.

The benefits of VSDs are widely recognized: optimal speed and control accuracy; reduced maintenance thanks to lower running speeds; higher production quality. Accordingly, there is a large number of VSD applications on the market, and approximately one half of new motor installations include a VSD.

Variable speed drives

10.1 Types of drives

Variable speed drives are power electronic devices which convert fixed input voltage, AC or DC, into variable voltage and frequency on the output side. The application determines whether a direct or indirect converter is used.

Converter
A converter is a variable speed drive converting fixed AC supply to variable voltage and frequency. It consists of four main parts: rectifier, DC circuit, inverter unit, and control unit. Converters are connected to an AC supply.

Inverter
An inverter is a variable speed drive converting fixed DC supply to variable AC voltage and frequency. It consists of two main parts: inverter unit and control unit. Inverters are connected to a DC source and are sometimes called common DC bus drives.

Direct converter
Direct converters such as cycloconverters and matrix converters change the input voltage and frequency directly to output without intermediate DC links. Cycloconverters are used in high-power (megawatt-level) applications and at low frequencies.

Indirect converters
Indirect converters are either current source or voltage source converters.In a voltage source converter (VSC), the most common converter topology in low voltage applications, the intermediate link acts as a DC voltage source, and its output consists of controlled voltage pulses at continuously varying frequency. The pulses are fed to the different phases of a three-phase system. This enables stepless speed control of the motor.

In a current source converter (CSC), the DC link acts as a DC current source, and its output is a current pulse or a current pulse sequence.

10.2 Pulse width modulation (PWM)

ABB low voltage VSC variable speed drives use pulse width modulation (PWM) with variable switching frequency, which best meets the majority of requirements. The used control method, such as direct torque control (DTC), vector control, or scalar control, depends on the product and application.

In a PWM drive, the rectifier converts the input line power, which has a nominally fixed voltage and frequency, into fixed DC voltage. This fixed DC voltage is then filtered to reduce the ripple voltage resulting from the rectification of the AC line. The inverter then changes the fixed DC voltage into AC output power with adjustable voltage and frequency.

10.3 Dimensioning the drive

DriveSize, a complete dimensioning tool for drives and motors, can be downloaded from www.abb.com/motors&generators. The following is a brief explanation about motor and converter selection with the DriveSize software.

Motor selection

The actual load torque should be below the reference loadability curve (or load capacity curve) of the selected motor and converter combination (see Figure 10.2 in Section 10.4). However, if the motor operation is not continuous in all duty points of the speed range, the load curve may exceed the reference curve. In this case, special dimensioning is required.

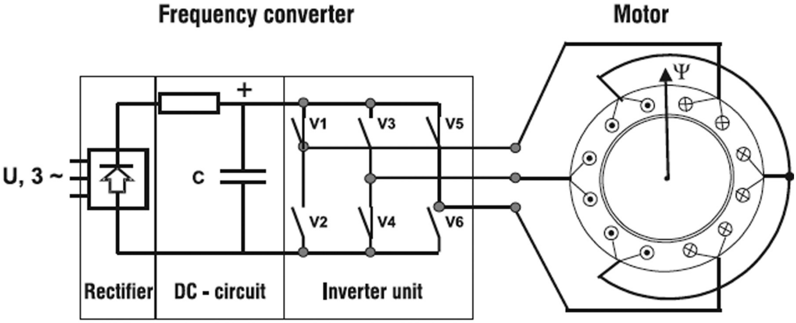
Further, the maximum torque of the motor must be at least 40 percent higher than the load torque at any frequency, and the maximum permissible speed of the motor must not be exceeded.

Motor design

Converters with different working principles, modulation patterns and switching frequencies give different performances for the same motor. As performance and behavior are also dependent on motor design and construction, motors of the same size and output power but different design may behave very differently with the same converter. Therefore, the selection and dimensioning instructions are product-specific.

Converter selection

The converter should be selected according to the nominal power P_N and rated current of the motor. Sufficient current margin should be reserved for controlling and managing dynamic situations.



—
Figure 10.1

—
Figure 10.1
The working principle of a VSD-driven motor

Figure 10.2. Reference curve for motor loadability with ABB's frequency converters (Process performance motors)

10.4 Loadability (torque)

Both theoretical calculations and laboratory tests show that the continuous maximum load (torque) of a converter-driven motor mainly depends on the modulation pattern and switching frequency of the converter, but also on the design of the motor. The graph below is a guideline for motor selection.

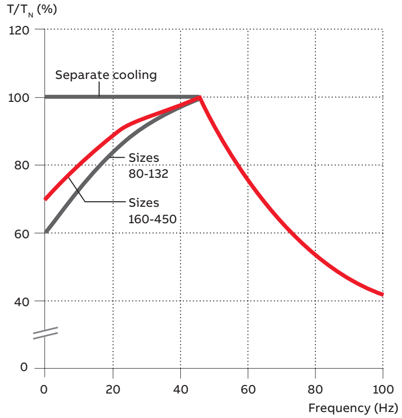


Figure 10.2.

These curves present the maximum continuous load torque of the motor as a function of frequency (speed) to match the temperature rise of the rated sinusoidal voltage supply at nominal frequency and full rated load.

ABB motors are usually designed to fall within temperature rise class B. Process performance motors (unlike motors for hazardous areas), for example, can in such cases be dimensioned either according to temperature rise class B curve, or temperature rise class F curve, which provides higher loadability. If the product catalog indicates that class F temperature rise applies on sinusoidal supply, in frequency converter use the motor can only be dimensioned according to the temperature rise class B curve.

The following ABB motors can be used with frequency converters:

- Process performance motors (designed for demanding industrial applications)
- General performance aluminum and cast iron motors (for general applications)
- Motors for explosive atmospheres: flameproof, non-sparking, and dust ignition protection motors
- Note: special motors such as synchronous reluctance motors, high speed motors and permanent magnet motors are always VSD-driven. Some of these require motor-type specific drives software.

10.4.1 Improving loadability

The output torque of frequency-converter-driven motors is usually slightly reduced because of heating caused by harmonics and a decrease in cooling at reduced voltage and lower frequencies. However, the loadability of the motor can be improved with the following means.

More effective cooling

More effective cooling is achieved by mounting a separate constant-speed fan, which is especially beneficial at low speeds. Selecting optimal fan motor speed and fan design to deliver a stronger cooling effect than with a standard motor at nominal speed will give an improved cooling effect over the entire speed range.

Liquid cooling (water-cooled motors) is another very effective cooling method. In very demanding circumstances the bearing end shields must also be cooled, for example by adding cooling disks on the shaft.

Filtering

Filtering the converter output voltage reduces the harmonic content of the motor’s voltage and current and therefore reduces the generation of additional losses in the motor. This reduces the need for derating. Full power of the drive and the speed range of the motor must be taken into account when dimensioning filters (additional reactance). However, filters may limit the maximum torque and speed of the motor. Filters also reduce electromagnetic noise, EMC, and voltage peaks.

10.5 Insulation level

In a frequency converter the output voltage (or current) most often is a voltage (current) pulse or a pattern of pulses. Depending on the type of power components and the design of the power circuit, considerable overshoot may develop at the leading edge of a voltage pulse. This is why winding insulation level must always be checked in product-specific guidelines. The basic rules for standard applications are:

- If the nominal voltage of the supply network is max. 500 V, no special insulation or filters are required for standard ABB induction motors.
- If the nominal network voltage is from 501 up to 600 V, special motor insulation or dU/dt-filters are required. But if the motor's supply cables are longer than 150 m, no special insulation or filters are required.
- If the nominal network voltage is from 601 up to 690 V, special motor insulation and dU/dt-filters are required. But if the motor’s supply cables are longer than 150 m, only special insulation is required.

Exact product specific guidelines can be found in ABB product catalogs.

10.6 Earthing

In converter usage, special attention must be paid to earthing arrangements to ensure:

- Proper action of all protective devices and relays for general safety
- Minimal or acceptable electromagnetic interference
- An acceptable level of bearing voltages to avoid bearing currents and bearing failures

ABB recommends using symmetrical shielded cables with cable glands providing a 360-degree connection (so-called EMC glands).

Table 10.1 Maximum speeds of Process performance motors

10.7 Operation at maximum speed

In converter usage, the actual speed of the motor may deviate considerably from its nominal speed. In operation at higher speeds, the maximum permissible speed of the motor type and the critical speed of the entire equipment must not be exceeded.

When the motor is run at higher than nominal speed, maximum torque and bearing construction should also be checked. Notice that if a standard fan is used, also friction and cooling losses as well as the noise level will increase.

	Speed r/min	
Frame size	**2-pole motor**	**4-pole motor**
71 - 80	6000	4500
90 - 100	6000	6000
112 - 200	4500	4500
225 - 250	3600	3600
280	3600	2600
315	3600	2300
355	3600	2000
400	3600	1800
450	3000	1800

Table 10.1

Maximum torque

In the field weakening area the voltage of the motor is constant, but motor flux and capability to produce torque reduce approximately in square of the frequency after the field weakening point (the point after which output voltage remains constant even though the output frequency increases). At the highest speed point, or at any other duty point in the field weakening area, the maximum (breakdown) torque must at least 40 percent higher than the load than the load torque to avoid excessive rotor heating.

If filters or additional reactances are used between the converter and motor, the voltage drop from the fundamental voltage with full load current must be taken into account.

Bearing construction

There is a limit to the speed at which rolling bearings can be operated. Bearing type and size, design, load, lubrication and cooling conditions as well as cage design, accuracy and internal clearance all influence the permissible maximum speed.

Lubrication

In general, the lubrication intervals are affected by the operating and ambient temperatures with respect to the lubricant and bearing component. Changing the bearings and/or lubricant may enable higher speeds. However, if this is done, the correct combination should be verified with ABB.

The sheer strength of the lubricant is determined by its base oil viscosity and thickener, which in turn determines the permissible operating speed for the particular bearing. The maximum speed can be increased by using high speed greases or oil lubrication. Very accurate relubrication with small quantities also reduces bearing friction and heat generation.

Fan noise

Fan noise increases with the speed of the motor and usually becomes dominant at 50 Hz for 2- and 4-pole motors. If the speed further increases, the noise level will also increase. The noise level increase can be calculated approximately with the following formula:

$$\Delta Lsp = 60 \text{ x } \log \frac{n_2}{n_1} \text{ dB(A)}$$

where Δ Lsp = increase of the sound pressure level when speed changes from n_1 to n_2.

Fan noise is typically ‘white noise’, which means that it contains all frequencies within the audible frequency range.

Fan noise can be reduced by either:
- Replacing the fan (and fan cover) with a reduced outer diameter fan
- Using a unidirectional fan
- Fitting a silencer

10.8 Balancing

The balancing accuracy and mechanical strength of all rotating parts should be checked if the permissible maximum speed of the motor is exceeded. All other parts mounted on the motor shaft, such as coupling halves and pulleys must also be carefully balanced.

10.9 Critical speeds

The first critical speed of the whole drive system, or of its components should not be exceeded, and a safety margin of 25 percent should be allowed.
Also supercritical drive systems can be used, but those must be dimensioned on case-by-case basis.

10.10 Shaft seals

All rubbing shaft seals (V-rings, oil seals, etc.) have a recommended maximum speed limit. If this is below the proposed high-speed operation, non-rubbing labyrinth seals should be used.

10.11 Low speed operation

Lubrication
At very low speeds, the motor's ventilation fan loses its cooling capacity. If the operational temperature of the motor bearings is ≥ 80 °C, (check by measuring the surface temperature of the bearing end-shields), shorter relubrication intervals or special grease (Extreme Pressure (EP) grease or high temperature lubricant) should be used.

The re-lubrication interval should be halved for each 15 °C increase in the bearing temperature above + 70 °C.

Cooling capacity of a fan
The air flow and cooling capacity depends on the fan speed. A separate constant-speed fan can be used to increase cooling capacity and motor loadability at low speeds. As the internal cooling is not affected by a separate outer fan, a small reduction in loadability is still necessary at very low speeds.

Electromagnetic noise
The harmonic components of frequency converter voltage increase the magnetic noise from the motor. The frequency range of these magnetic force waves can cause structural resonance in the motor, especially in steel-framed ones.

Magnetic noise can be reduced by:
- Increasing the switching frequency, giving higher order harmonics and lower amplitudes which are less disturbing to the human ear. On the other hand, setting to a high switching frequency may reduce the output current of the drive.
- Filtering the harmonic components at the converter output filter or in additional reactances
- Motor silencer

More information on noise reduction can be found in Chapter Noise.

Notes

Notes

For more information please contact
your local ABB representative or visit:

abb.com/motors&generators

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