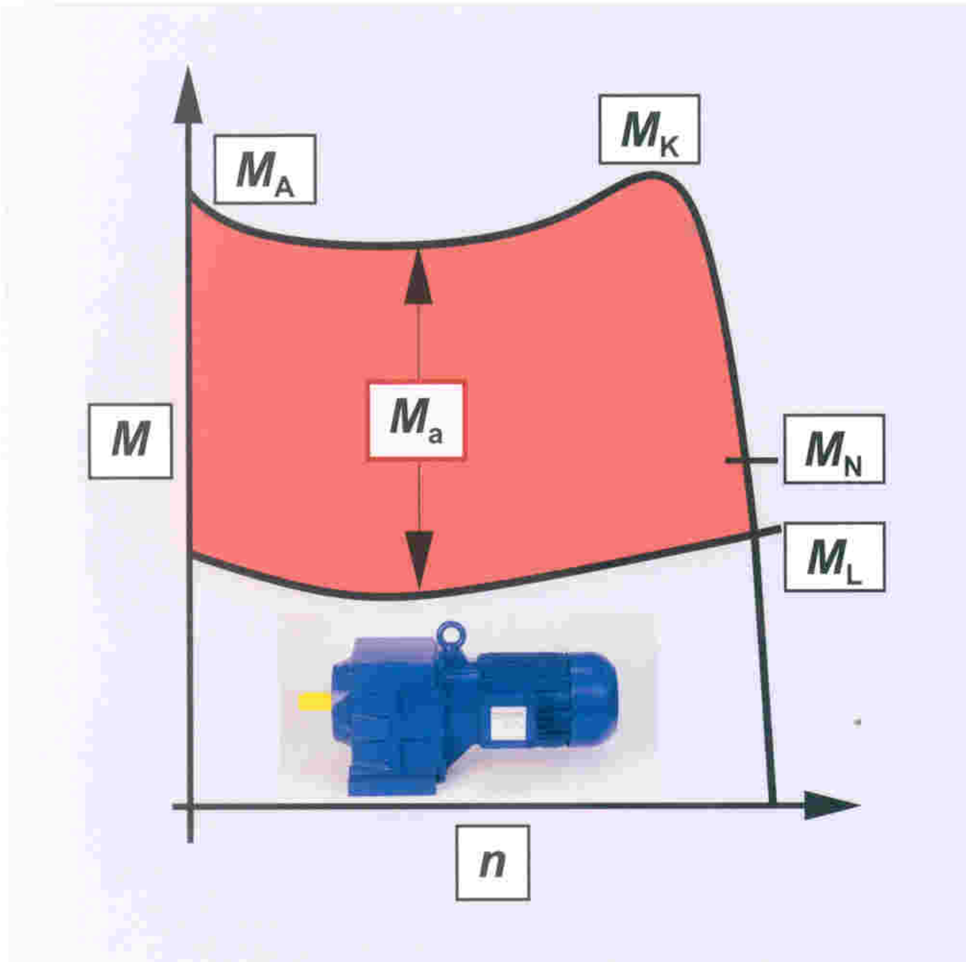
Danfoss

Electrical drives with geared motors



BAUER geared motors

VLT® frequency converters

Helmut Greiner

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VLT® frequency converters

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FOREWORD

Until about the year 1930 there was a problem in choosing an electric single drive in that electric motors obtain their output through relatively high speeds and correspondingly low torques; this meant that open retrospective gear reduction was necessary – usually in the form of a “belt drive gear”. In the first, mostly hand-crafted “geared motors”, the electric motor and retrospective gear reduction were designed together. The conventional motor was the basis for an integrated single-stage gear unit and was called a “back-geared motor” or “electric motor with gearhead”. In the bigger, multi-stage gear units the gear unit was then the basis and the design that is common today emerged, wherein the input shaft and output shaft are arranged “in-line” and which the user knows as a “slow running electric motor”.
Today geared motors are an important aspect of drive technology; depending upon the industry they constitute between 25 and 75 % of the total number of electric motors. They are produced and offered in catalogues with rated outputs up to about 100 kW and with speeds ranging from less than 1 r/min to just under 750 r/min in a modular design and in series.
Usually one of the various forms of three-phase motor is used as the “prime mover”. Frequency adjustment via a static inverter is the most common means of seamlessly adjusting or controlling the speed – for small outputs up to currently 7.5 kW it is now also possible with an integrated inverter in the form of an “inverter-fed motor”. The DC shunt motor is to a large extent detached. The mounting size of the motors is mostly subject to the demand for as compact a design as possible; no “standard motors” are used. In all other respects, however, the far-reaching standards for electrical machines are observed.

Compared with the motors there is a considerable degree of freedom in the design and utilisation of gear units, which are determined only by the requirement that they should be optimally suited structurally to the purpose for which they will be used and by the demands that a quality product should be reliable and have a long service life. Alongside the helical-gear unit with concentric drive which dominates the German market with a share of about 40 %, the shaft-mounted flat-gear unit, bevel-gear unit and worm-gear unit share the rest of the market roughly equally.

The book deals in a practical way with the criteria for dimensioning, choosing and using geared motors – it reflects some aspects of 50 years of experience and expertise acquired in this field.

Aichschieß, March 2001 Helmut Greiner

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I GEARED MOTORS

1 Low speed drives

There are various objectives achieved by adapting the driving speed to the requirements of the working process, including:

- ☐ Optimising the process
- ☐ Minimising costs
- ☐ Reducing the transmission losses
- ☐ Improving safety at work.

1.1 Speed requirement – speeds offered

The three-phase cage induction motor can be regarded as the “industrial drive”:

- ☐ About 70 % of all industrial drives are of this motor type.
- ☐ About 25 million drives of this type are operating in Germany.

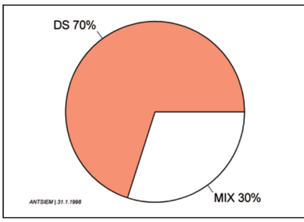


Figure 1.1.1
Proportion of three-phase motors according to the production value of industrial drives produced in Germany
DS – Three-phase motors
MIX – Others

Source: ZVEI (2000)

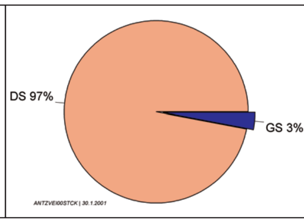


Figure 1.1.2
Proportion of three-phase motors of the number of motors produced in Germany
DS – Three-phase motors
GS – DC-motors

Source: ZVEI (2000)

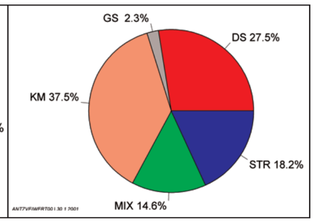


Figure 1.1.3
Proportion of electric drive systems to the value produced in Germany
DS – Three-phase motors
GS – DC-motors
KM – Small-power motors
STR – Converters
MIX – Others
Source: ZVEI (2000)

The benefits of this type of drive cannot be ignored; they are unavoidably linked to the definition of output speed as given by:

$$n = \frac{60 \cdot f}{p} - \Delta n$$

n – Full load speed in r/min
f – Supply frequency in Hz
p – Number of pole pairs (usually between 1 and 6)
Δn – Slip speed in r/min

Number of poles	2	4	6	8	12
Synchronous speed at 50 Hz (r/min)	3000	1500	1000	750	500
Rated speed at 50 Hz (r/min) (depending on the motor size)	2750 ... 2980	1300 ... 1450	830 ... 990	650 ... 740	440 ... 485
Synchronous speed at 60 Hz (r/min)	3600	1800	1200	900	600
Rated speed at 60 Hz (r/min) (depending on the motor size)	3200 ... 3520	1600 ... 1760	1020 ... 1170	780 ... 870	530 ... 590

In contrast to the limited choice of speeds ***offered*** by standard motors, there is a wide range of speeds ***required*** – usually in industrial technology far lower speeds are required than those produced by motors.
An example from materials handling is given as a typical case: If the manual "conveying system" illustrated in **Figure 1.1.4** were to be replaced by a "direct-driven" conveyor belt, the flat tiles would arrive at their point of destination at a speed of 19 m/s = 68 km/h.
Practicable "material handling" requires a driving reduction by a factor of 30 in order to achieve a speed of 50 r/min: The operating speed must be adapted!

Figure 1.1.4
"Conveying system" for flat tiles, seen in South Tirol

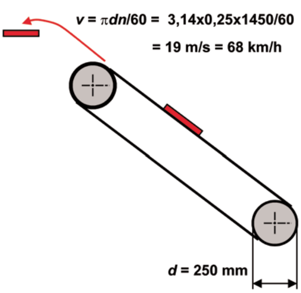
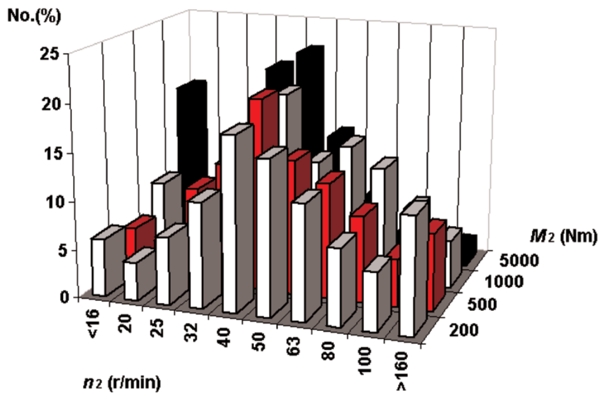


Figure 1.1.5
Replacement of the conveying system with a conveyor belt with direct drive 1450 r/min

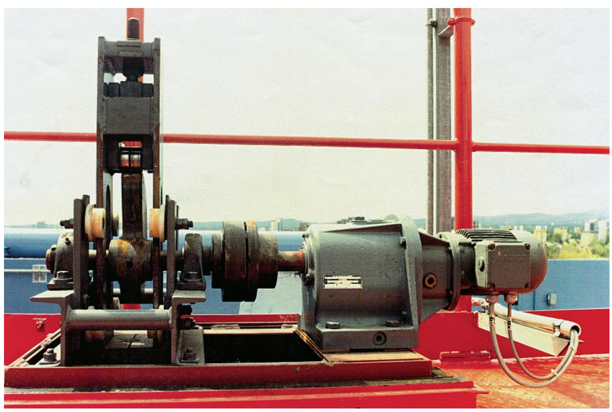
Actually the demand of output speeds centres on 40 ... 50 r/min, as shown in the Danfoss Bauer delivery statistics (**Figure 1.1.6**) for geared motors. This speed range has dominated the entire product range, i.e. all kinds and sizes of geared motors, for about five decades!

Figure 1.1.
Danfoss Bauer delivery statistics for geared motors for output speeds (n_2) and torque (M_2) on the output shaft with a characteristic centre of demand at about 40 ... 50 r/min



The wide field of application of geared motors – from the "Knocker" to the "Cooling tower fan" (**Figures 1.1.7** and **1.1.8**) requires speeds from below 1 r/min to almost 1000 r/min.

Figure 1.1.7
Knockers to clean spray electrodes on LURGI dust filters with typical speeds of < 1 r/min



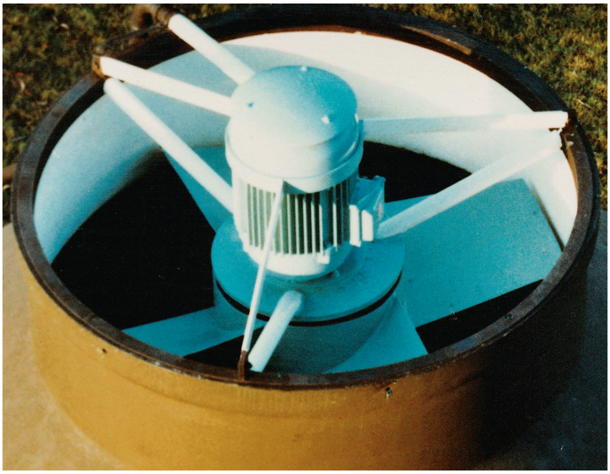


Figure 1.1.8
Cooling tower fan with typical speeds of 350 ... 750 r/min

Therefore the range of speeds offered for geared motors in the catalogue is wide and finely differentiated.

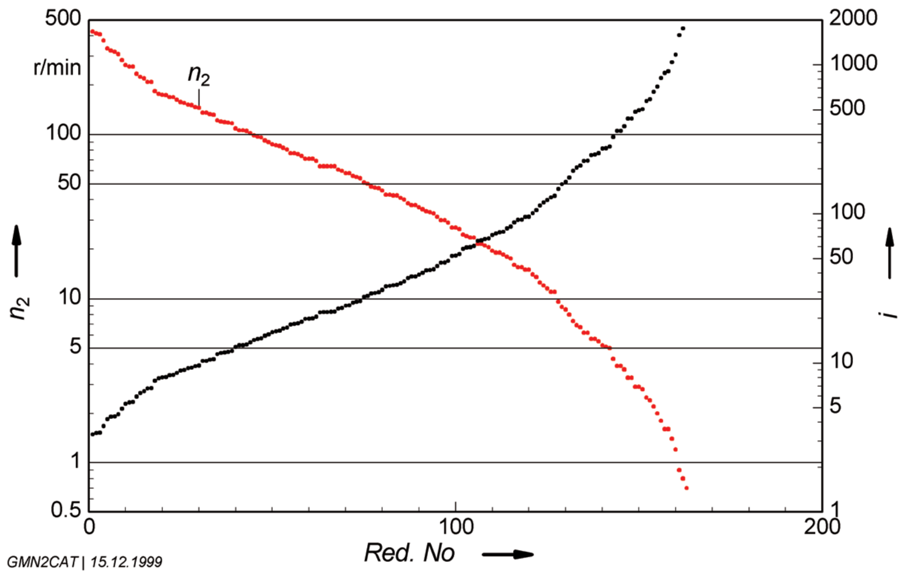
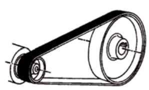
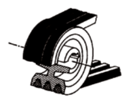


Figure 1.1.9 In the standard module 163 pairs from the reduction ratio *i* and output shaft n_2 are available on 4-pole motors with a rated power of 0.75 kW

1.2 Chain and belt drives

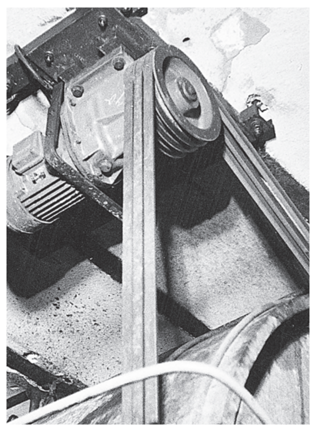
Gear units with flexible traction element sare the simplest and most cost-effective method in the speed range of 700 ... 3000 r/min, of obtaining speeds between 750/1000/1500/3000 r/min as fixed by the motor [Source: *Niemann/Winter:* Machine elements I].

				
System	**Flat belt**	**V-belt**	**Toothed belts**	**Chain**
Reduction ratio i_{max}	5	8	8	6
Efficiency η **(%)**	96 ... 98	92 ... 94	96 ... 98	97 ... 98
Slip ***s*** **(%)**	1 ... 2	1	0	0

The nominal efficiency of traction element gear units comes close to the values for gear trains. The efficiency is of most interest in the case of multiple reduction ratios (**Figure 1.2.3**).
Arguments for using closed oil-lubricated gear units:
- ☐ Fouling and moisture
- ☐ Noise
- ☐ Maintenance costs
- ☐ Protection against access.

Figure 1.2.1
Open chain transmission gearing on a drive producing fish meal without using expensive protective guards

Figure 1.2.2
Belt drive with extremely high reduction ratio (pre-tensioning) in the humid and aggressive environment of a tannery



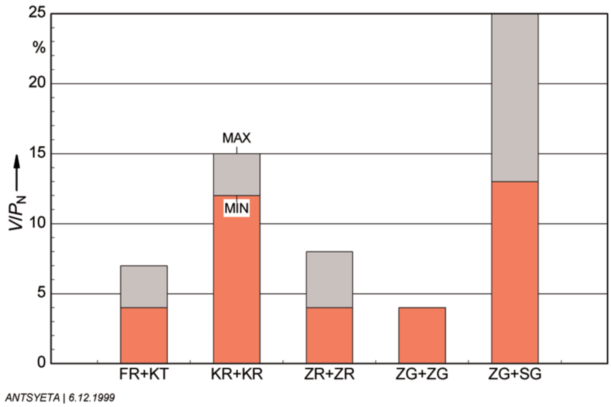


Figure 1.2.3
Transmission losses V of various types of gear unit construction to achieve a speed of approximately 40 r/min on a 4-pole drive motor; reduction ratio $i = 35$

FR+KT	Flat belt	approx. 1:5 with an efficiency	min.	0.96
			max.	0.98
	Chain	approx. 1:7 with an efficiency	min.	0.97
			max.	0.98
			overall	0.93 ... 0.96
KR+KR	V-belt	approx. 1:5 with an efficiency	min.	0.92
			max.	0.94
	V-belt	approx. 1:7 with an efficiency	min.	0.92
			max.	0.94
			overall	0.85 ... 0.88
ZR+ZR	Toothed belt	approx. 1:5 with an efficiency	min.	0.96
			max.	0.98
	Toothed belt	approx. 1:7 with an efficiency	min.	0.96
			max.	0.98
			overall	0.92 ... 0.96
ZG+ZG	Helical gear	approx. 1:7 with an efficiency	approx.	0.98
		approx. 1:5 with an efficiency	approx.	0.98
			overall	0.96
ZG-SG	Helical gear	approx. 1:7 with an efficiency	approx.	0.98
	Worm gear	approx. 1:5 with an efficiency	min.	0.77
			max.	0.89
			overall	0.75 ... 0.87

1.3 Economic speed limits of three-phase motors

The following important relationship applies for the torque developed by an electric motor

$$M \sim \Phi \cdot I_2$$

For an induction motor this law can be converted to

$$M \sim \Phi^2$$

M – Torque generated
Φ – Magnetic flux
I_2 – Current in armature

Since the magnetic saturation of any increase in the magnetic flux sets limits, greater flux can only be achieved through increased use of the active material: Thus for a given power output the frame size and cost of an electric motor must increase in proportion to the higher torque required or the lower desired speed. **Figure 1.3.1** illustrates this with the example of three standard frame sizes 22 kW rated output with speeds of 1500, 1000 and 750 r/min.
Figure 1.3.2 shows that even at a speed of about 700 r/min a faster running 4-pole motor with a single-stage reduction gearing requires less space than an 8-pole motor without a gear unit. However, this is provided that the compact integral form of construction described in section 1.4 is used.

Figure 1.3.1
Comparison of motor frame sizes at a rated output of 22 kW with speeds of 1500 r/min (4-pole), 1000 r/min (6-pole) and 750 r/min (8-pole).

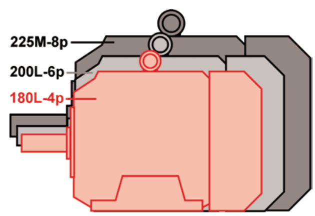
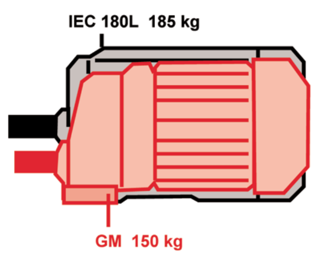
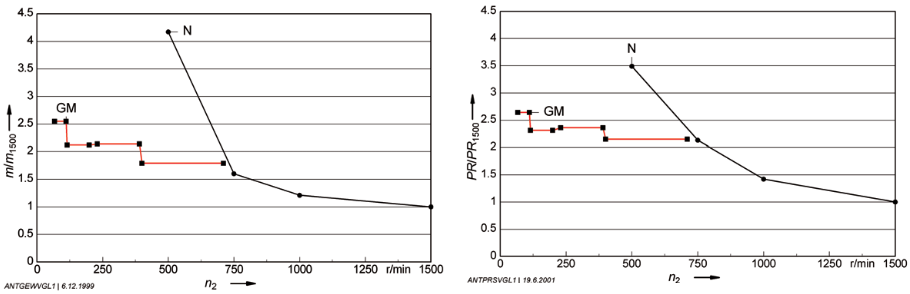


Figure 1.3.2
Comparison of weight and space requirement between standard motor (IEC 180L) and geared motor (GM) for rated output of 11 kW and rated speed of approx. 700 r/min.



Though in some cases such comparisons can be less clear for other rated outputs, the price comparison in Figure 1.3.3 shows that the geared motor's economic advantages increase as the required speed decreases.



Weight

Price

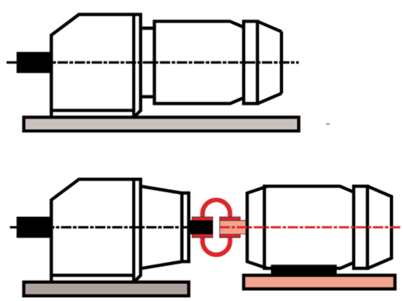
Figure 1.3.3 Price (PR) and weight (*m*) comparison between standard motor (N) and geared motor (GM) with rated output of 5.5 kW.

Corresponding values refer to 4-pole standard motors

1.4 Important constructional features of geared motors

The combination of a high-speed electric motor with a reduction gearbox into a single drive unit (the geared motor) requires careful matching of the motor and gearing to achieve the best design. **Figure 1.4.1** clearly illustrates the advantages of a geared motor over a separately mounted motor and gear unit.

Figure 1.4.1
Comparison of the space requirements and installation requirements for a geared motor and a separately mounted motor and gear unit



Figures 1.4.2 and **1.4.3** show a tried and tested design in which the motor and gear unit are completely joined together at a two-part intermediate cover. This part not only provides a special flange for the motor but also a drive-side end cover for the gear unit, thus making it a particularly compact and space-saving construction.

Figure 1.4.2
Section of a three-phase helical-geared motor

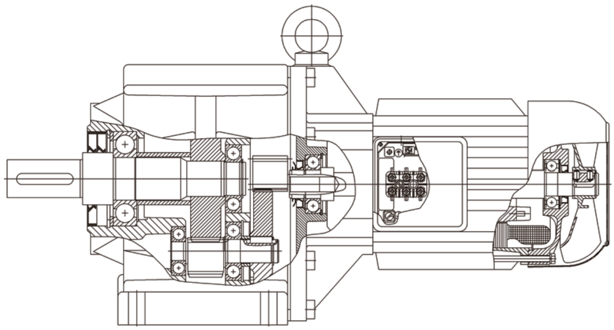
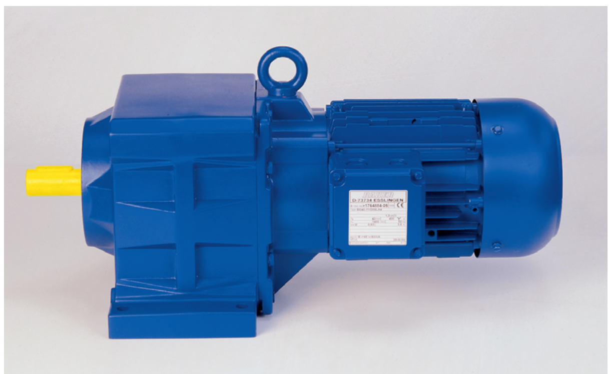
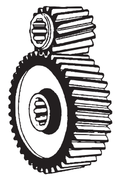
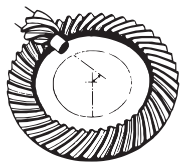
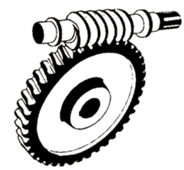


Figure 1.4.3
View of a three-phase helical-geared motor



1.5 Gear train

Helical-gear and worm-gear units for the wide range of speeds handled in section 1.1 in various types of construction and numbers of steps with reduction ratios of approximately i = 3 ... >10,000 are offered as standard.

Characteristic value per stage according to *Niemann/Winter*: Machine elements I			
	Helical gear	**Bevel gear**	**Worm gear**
i_{max}	approx. 7	approx. 5	approx. 50
η **(%)**	approx. 98	approx. 98	approx. 50 ... 96

1.6 Range of gear unit sizes

For a given rated output, which is represented in the "geared motor" combination by the electric motor, the same picture is inevitably produced for the rated torque in the wide speed range with its closely-spaced steps as described. Since the size of the gearing will be determined by the magnitude of the ***torque*** to be transmitted, a whole range of gear units must be allocated to the electric motor for different rated torques. Figure 1.6 shows a section of the standard combinations for a geared motor and illustrates how the size of the gearbox is graded according to torque so as to enable optimum matching to the driven machine according to economic constraints.

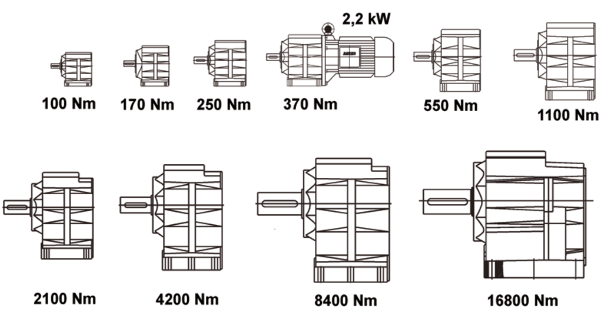


Figure 1.6
Example of possible geared motor combinations for size D09 motor (max. 2.2 kW) with gearboxes graded in size, according to their torque rating shown in Nm

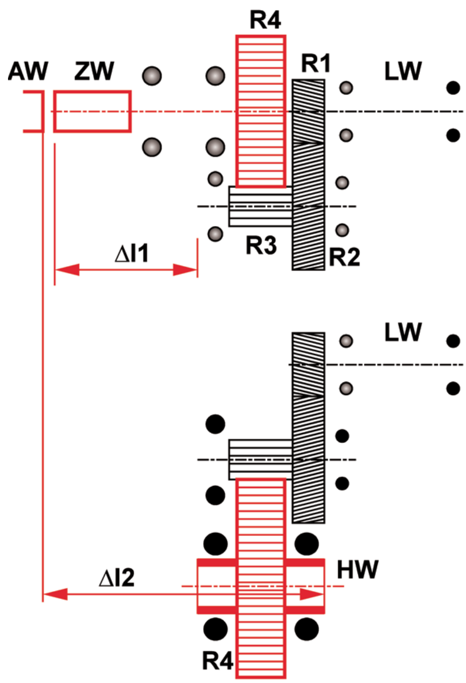
1.7 Gearbox types and space requirements

Dimension guidelines are laid down both for the electrical and mechanical components of geared motors. These are taken either from standards and regulations or are determined by a designer to ensure a quality product achieves the service life required.
Therefore it will not be possible to reduce the overall dimensions for specific nominal data below a certain minimum size. However, the dimensions can be arranged in various ways so that the designer can "save space" in the most critical position.
This applies in particular to ***shaft-mounted gear units*** where the omission of the coupling and mounting base means that the axial dimension can actually be reduced further than with other solutions.

Since the geared motor was "discovered", the low-speed output shaft has tended to be arranged as the solid shaft concentrically to the rotor shaft (**Figure 1.7.1**).
The reason for this is obvious: For the user, the unit represents a ***low-speed motor***. The user is not particularly interested in the way and in which internal mounting the ***speed reduction*** is achieved.

Figure 1.7.1
Principal mounting of wheels and shafts in the classic geared motor with concentric output shaft
(in-line mounting, top)
and shaft-mounted geared motor
(with hollow shaft, below)

LW	Rotor shaft
ZW	Solid shaft
AW	Driven shaft
HW	Hollow shaft
R..	Pinion and wheel
R4	End wheel (on shaft-monted gear unit usually with increased diameter)
Δl1	Reduced casing
Δl2	Reduction with shaft-mounted casing



The advantages of the “shaft-mounted gear unit” principle was rediscovered in recent decades. Since the hollow shaft (HW) requires access on both sides, the end wheel (R4) cannot be “folded back” into the centre of the running axle (LW). R4 must generally maintain a larger diameter to create the space required for the bearings of the hollow shaft. The drive unit can be “flatter” by the $\Delta l1$ amount. As the hollow shaft is placed directly on the shaft to be driven (AW), the space saved is actually $\Delta l2$.
The new term ***flat-gear unit*** was introduced and adopted by many manufacturerers for the familiar design.

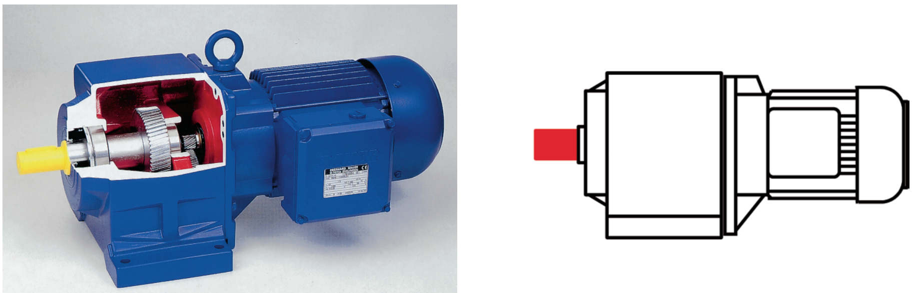


Figure 1.7.2
Classic geared motor with output shaft arranged concentrically to the motor shaft

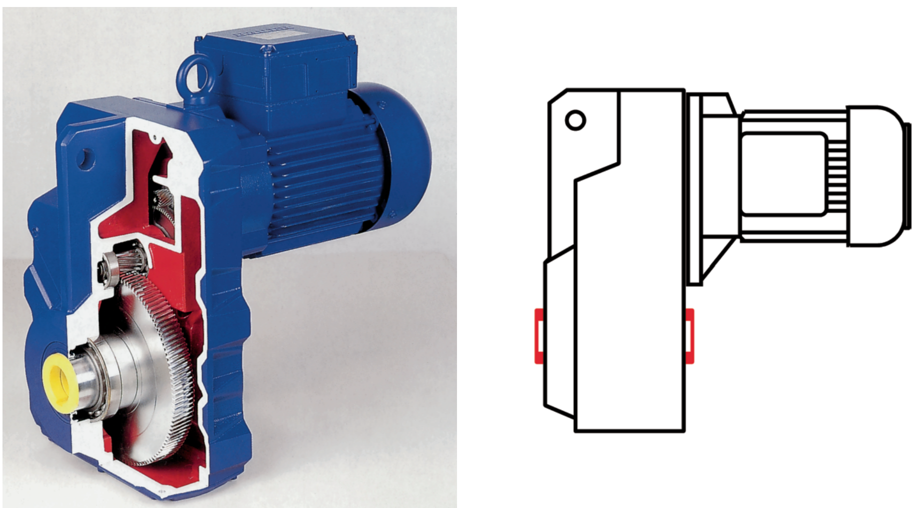


Figure 1.7.3
Shaft-mounted geared motor with hollow shaft

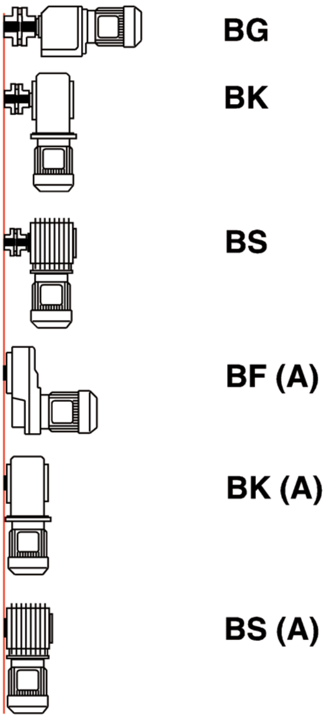


Figure 1.7.4
Comparison of the space requirements for different models

BG – Helical-geared motor
BK – Bevel-geared motor
BS – Worm-geared motor
BF – Flat-geared otor
.. (A) – Shaft-mounted version

Figure 1.7.5
Shaft-mounted bevel-geared motor on a container.

Cost-effective solution compared to fitting a foot-mounted geared motor with coupling and support.

2 Rated torque

For electrical drives with relatively low rotational or linear speeds, the torque often gives a better indication of the size of drive required than the power rating.
Thus a 215 mm drum motor giving a peripheral speed of 0.038 m/s rated at only 75 W produces a rated torque of 215 Nm and produces a belt tension of about 2000 N. The belt pull required can usually be determined quite easily with a spring dynamometer.

2.1 Calculation of rated power from the torque

$$M = F \cdot r$$

$$P = \frac{M \cdot n}{9550}$$

M – Torque in Nm
F – Force in N
r – Lever arm (radius) in m
P – Power in kW
n – Rotational speed in r/min

2.2 Power consumption at various speeds

The torque required by many machines is mainly made up of lifting and friction torques (see sections 6.1 and 6.2) and is nearly constant for all speeds. The power requirement therefore increases or decreases with the speed of the conveyor.

2.3 Calculation of rotational speed from the linear speed

$$n = \frac{60 \cdot v}{\pi \cdot d}$$

n – Rotational speed at the drive station in r/min
v – Linear speed in m/s
d – Diameter on the driving element‘s application of force in m (e. g. drum diameter)

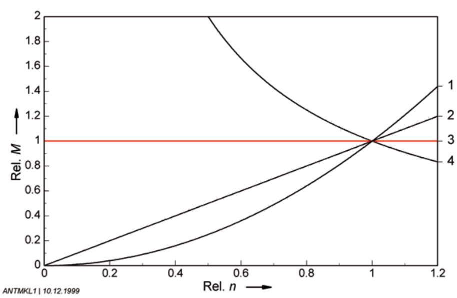


Figure 2.3
Typical torque-speed characteristic curves of driven machinery.
1 – square (pumps, fans)
2 – linear (calendars, sheet rollers),
3 – constant (hoists, conveyors),
4 – inverse (coil winders, machine tools)

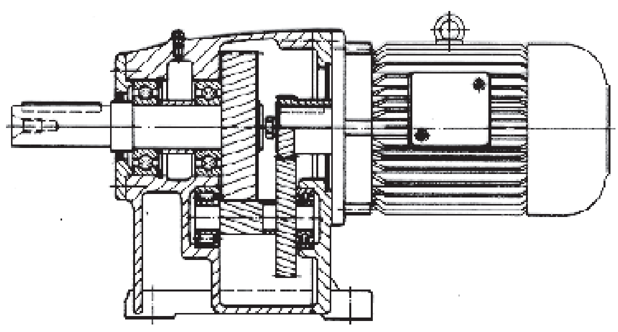
3 Standard motors on gear units

Despite the unsuccessful experiment to introduce a standard dimensioned motor (DIN 42670 in 1948) three-phase cage motors were made in Germany up to the 1950s with connection dimensions specific to each manufacturer. In the magazine „Elektro-Jahr“ in 1957/58, W. Egli reported that at BASF there were no fewer than 80 types in operation differing in their principal data for an output of 1.5 kW at 1500 r/min. Consequently DIN 42673, which appeared in December 1960 with standardised connection dimensions and power outputs for 2, 4, 6 and 8 pole motors with shaft heights of 56 to 315 mm, was a great step forward, especially for users; to date, i.e. some 40 years later there have been no fundamental changes or possible improvements to this standard as far as interchangeability is concerned. ***Even the current standard, EN 50347, reiterates the old dimensions and power outputs under a new number of the Standard.***
The range of dimensions is based on IEC Recommendation 72-1, in which, however, no power output is established; for that reason there is no such thing as an ***IEC motor*** with global validity.
It is therefore understandable that mainly the major users – e. g. those in the chemicals industry, automotive manufacturing and process manufacturing – consistently ask for gear units mounted with standard motors. They expect to find that a replacement motor can be made available extremely quickly from the general stock if of a motor breaks down.
The following explanations indicate that there is a limit to such expectations.

3.1 Direct mounting of a flange motor

Figure 3.1 shows a design in which a DIN flange motor has been mounted directly onto the gear unit.

Figure 3.1
Standard flange motor mounted directly onto the gear unit



There are numerous disadvantages to mounting in this way.

3.1.1 No oil seal or inadequate oil seal

Standard motors do not usually have a special shaft seal. Even what is referred to as an oil-tight version (a simple shaft seal) does not have the long-term sealing properties that can be expected from a properly designed integral geared motor.

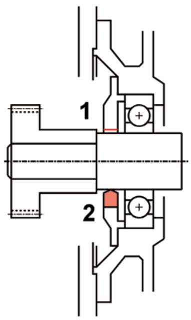


Figure 3.1.1.1
Seal at shaft head of a standard flange motor on a speed-transforming gear

1 – Normal version
non-oil-tight gap seal
2 – Special version
oil-tight bearing flange

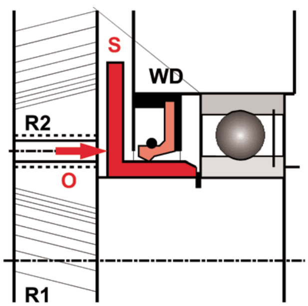


Figure 3.1.1.2
Principle of the seal between the motor and gear unit in an integral design

WD – Shaft seal
S – Centrifugal disc (labyrinth plate)
R1 – Pinion
R2 – Gearwheel
O – Oil jet
(strength and direction dependent on peripheral speed, helix angle, direction of rotation etc.)

3.1.2 Unnecessarily long shaft end

The length of the shaft end of standard motors was designed for flat pulleys in accordance with DIN 111 (**Figure 3.1.2.1**).

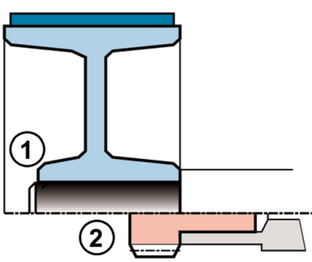
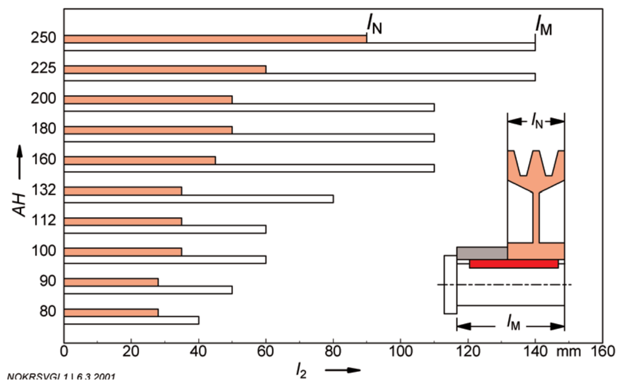


Figure 3.1.2.1
Comparison of the actual length of the shaft end with the axial space requirement for an integral geared motor

1 – Shaft end in accordance with DIN 42946
2 – Plug-in pinion for integral geared motor

They are far too long even for the V-belt pulleys used today, and especially for power transmission through gearwheels (**Figure 3.1.2.2**). The reasons stated at the beginning of Section 3 have prevented the long overdue changes that correspond with the present state of the art.

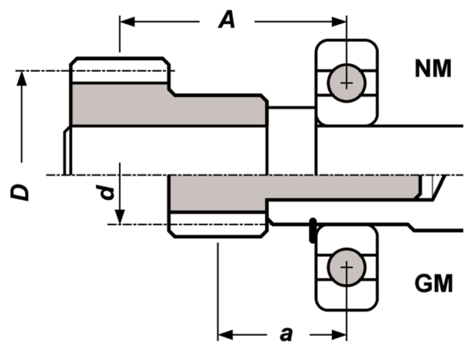
Figure 3.1.2.2
Comparison of standard lengths of motor shaft extension l_M in accordance with DIN 748 / DIN 42946 and hub l_N of narrow V-belt pulleys in accordance with DIN 2211 for standard motors in accordance with DIN 42673 (EN 50347) with shaft height AH 80 to 250



The long shaft end of the standard motor forces the pinion to be mounted in the wrong location, whereby bad tolerances and/or shocks have a negative impact on the meshing (**Figure 3.1.2.3**).

Fig 3.1.2.3
Comparison of the distances from the bearing to the application of force in the pinion for

NM – Standard motor (A)
GM – Integral geared motor (a)



3.1.3 Unnecessarily thick shaft end
The large diameter (*D* in Figure 3.1.2.3) of the standard shaft extension also leads to considerable disadvantages by comparison with the integral design: Compared with GM, the SM design, with a shaft-centre distance AA determined by space requirement and costs, results in

- ☐ a lower reduction ratio in Stage I, therefore three stages instead of two at, for example, 50 r/min
- ☐ higher tooth number, therefore an unsatisfactory meshing frequency (**Figure 3.1.3.1**).

For details see SD 1800 “Measurement and Evaluation of Machine Noises”.

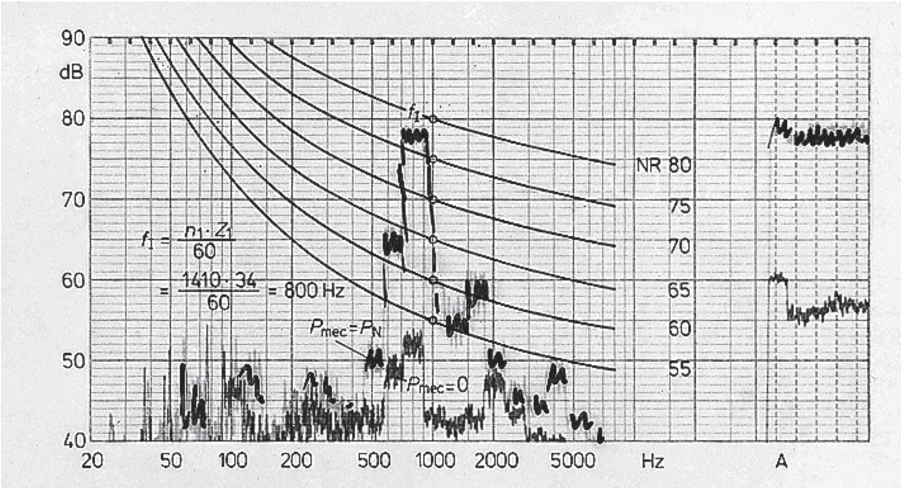


Figure 3.1.3.1
Frequency range of the noise level under full loading for a gear unit mounted with a standard motor;
NR = Noise Rating 78; pinion tooth number: 34

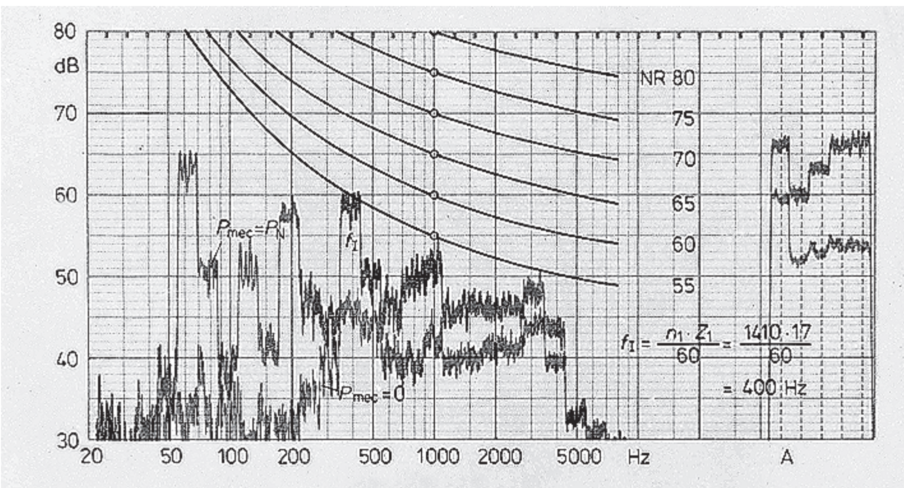


Figure 3.1.3.2
Frequency range of the noise level under full loading for a Danfoss-Bauer geared motor designed as a single unit;
NR = Noise Rating 55; pinion tooth number: 17

3.2 Adapter mounting of a flange motor

The advantages of a geared motor compared with a separate mounting arrangement of motor and gear unit have been discussed in detail in Section 1.4. The disadvantages of direct mounting as in Section 3.2 can be avoided if the flange motor is mounted by means of an adapter and the input shaft of the gear unit is driven by means of a special coupling. As the coupling has to be joined "blind" and should be easily detachable when dismantled, Danfoss Bauer has developed a solution as shown in **Figure 3.2.1** which has the following advantages:

1 Adapter face for driving into the gear unit as for an integral geared motor
2 Plug-in coupling with short overall length despite a long motor shaft
3 Plug-in coupling easy to connect and release with a fixing screw
4 Fixing screw accessible from outside.

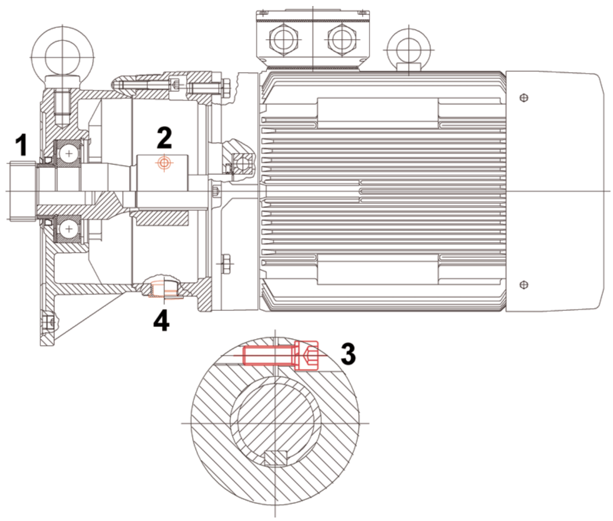


Figure 3.2.1
Sectional drawing of an adapter for mounting DIN or NEMA flange motors by means of a plug-in coupling

Details in text

Design:
Danfoss Bauer

The adapter can be used within the modular system for all four types of gear unit as shown in **Figure 3.2.2**.

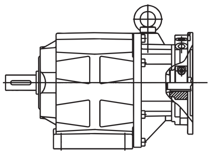
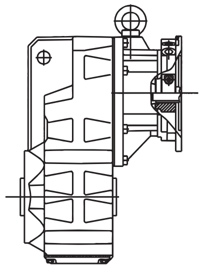
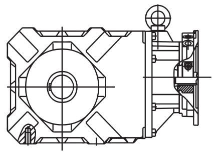
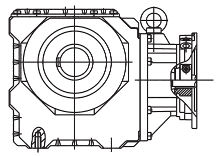
BG	BF	BK	BS
Helical-gear unit	Flat-gear unit	Bevel-gear unit	Worm-gear unit
			

Figure 3.2.2 Multiple use of the adapter for mounting a flange motor to various types of gear unit

Even given the adapter's compact design as described, depending on the size of the type used there is an additional length of 15 ... 20 % in comparison with the overall length (shaft end to air intake) in the case of the integral construction. These additional expenses are also reflected in corresponding additional prices. In the version shown in **Figure 3.2.3** the coupling housing takes up an additional length of 25 ... 33 %.

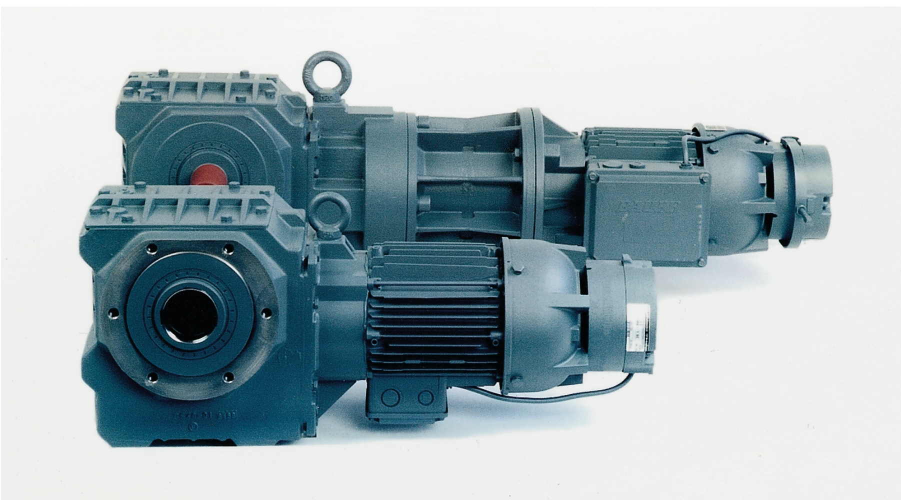


Figure 3.2.3 Geared motor of integral construction (front) compared with a gear unit with a standard flange motor mounted over adapter and coupling

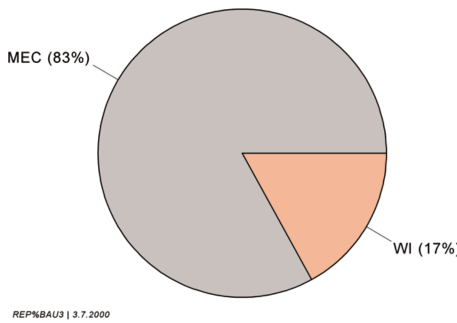
3.3 Correct spare provision: Motor part or geared motor?

If the demand for exchangeable standard motors springs from concern about readiness for service in the event of a fault, the rightness and completeness of this measure must be analysed:

- ☐ Are oil-tight flange motors for direct mounting actually kept in stock?
- ☐ Can the mostly 4-pole standard replacement motors replace the frequently used special geared motors (pole-changing, with built-on brake, for soft starting) from the point of view of power transmission engineering?
- ☐ Is the provision made for the motor part sufficient? Experience shows that mechanical damage mainly occurs because the gear unit cannot be adequately protected against overloading! (See Part VIII and the Danfoss-Bauer book “Protective measures for three-phase geared motors”).

Figure 3.3
Relative proportion of main components in the overall repairs of Danfoss-Bauer geared motors

MEC Gear parts
WI Winding



3.4 Conclusion

As a means for improving the availability of an installation that is important to the operation, the use of gear boxes with a standard motor mounted is inadequate. Keeping stocks of the same make of replacement geared motors is recommended.

For mounting special motors that are used in relatively small numbers (e. g. explosion-proof motors in a flameproof type of protection, motors complying with special regulations) this variant to the integral geared motor can make sense. However, it requires more space and costs more. The motor can be mounted and dismounted “dry” and therefore does not need an oil-tight bearing flange on the shaft extension.

4 Catalogue representation of geared motors

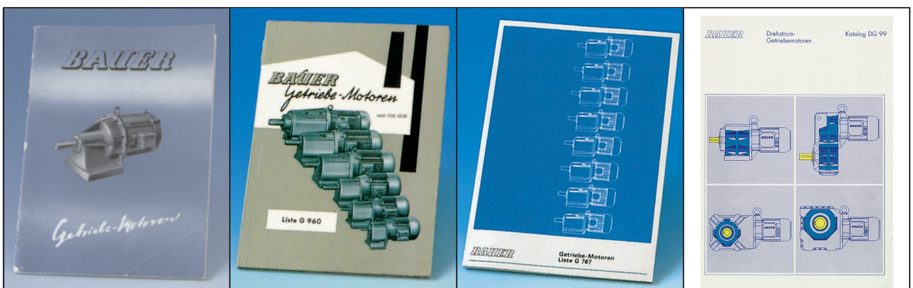
The introduction of the new generation of geared motors “Danfoss Bauer 2000” provided the reason for tracing the development of the product over 60 years with the help of the first catalogue for three-phase geared motors dated 1940. It is true that the company had already begun to produce geared motors manually shortly after 1927 but the gearwheel design was initially “tailor made” to the individual wishes of the buyer.

Through the first catalogue a successful attempt was made to offer a choice of a relatively narrow grading of output and speed to suit the most common requirements. The catalogue range offered many advantages:
- ☐ Optimised gear design
- ☐ Prefabricated gearwheels
- ☐ Comprehensive, clearly presented manufacturing programme
- ☐ Extended range of customers
- ☐ Clear pricing policy.

The new catalogue was quickly accepted within the company – and amongst what was, at the time, a very small number of competitors. In the meantime Danfoss Bauer has published the 30th generation of its catalogue – with an optional CD version with computer selection and search programs. It is not merely interesting from a company history point of view to compare various aspects of the way the catalogues have presented a series produced product over the course of 60 years.

4.1 Title graphics

From the outset the product served as an eyecatcher – initially presented individually, then shown in various ways to demonstrate clearly that it was produced in quantity. Today‘s title page aims to show the modular principle and the possible variations resulting from it.



1940	1960	1967	1997

Figure 4.1.1 Title graphics of the catalogues for geared motors 1940 – 1997

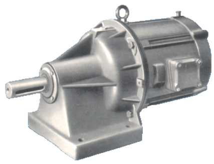
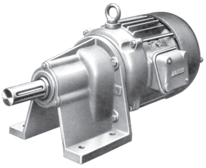
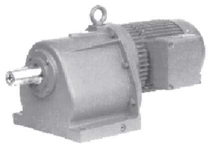
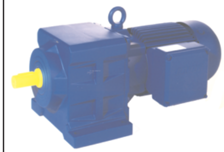
			
1940	1960	1980	2000

Figure 4.1.2 Function, production and modules determine the design

4.2 Technical description

Even though the technical design and the potential uses of the geared motor have changed during the six decades in which it has been included in the catalogue, the basic concept and the benefits of this form of drive have remained the same. For that reason, although the style and manner of expression of the relevant passage in the first catalogue may appear antiquated – the aim still remains modern:

Technical information
The geared motor is increasingly prevalent throughout industry and in many cases has already become an indispensable design element on account of its known advantages. The following special requirements must be met: Compact and therefore space-saving structure, moisture resistance and in particular resistance to atmospheric exposure, absolute operational reliability with detailed design of all parts, minimum noise levels when running. The BAUER geared motor, developed over a period of more than 10 years on the basis of accumulated experience, satisfies these demands in full.

Figure 4.2 Text extract from the first catalogue, 1940

4.3 Power range

The motor rated outputs offered between 0.18 and 22 kW (0.25 and 30 HP) were graded according to DIN 42971 (previously DIN VDE 2650). The range was indeed significantly smaller than that in the catalogues available today but amply covered the practical requirements of the time.

4.4 Speed range

It is also possible to observe a significant expansion in the listed speeds offered, the demand at the extremes of the range offered, however, in other words essentially below 10 r/min, being in fact relatively small.

This begs the interesting question of whether the speeds of geared motors have increased. Unfortunately, the relevant statistics for the 60 year period under consideration here are not available.
A comparison between 1970 and 2000, i.e. over a period of 30 years, shows, however, that there has been no conspicuous shift and that the most frequently demanded speed for a geared motor is approximately 50 r/min (see Figure 1.1.6).

4.5 Number of gear unit sizes

The range of rated torque offered from about 175 to about 4600 Nm was covered by 9 gear unit sizes; this corresponds to a theoretical progressive ratio of approximately 1.45.
For the range of torque offered nowadays for a series of gear units of approximately 20 to 8400 Nm, 12 gear unit sizes are used; this corresponds to a theoretical progressive ratio of approximately 1.65.
This tallies extremely well considering the complex associations – resulting from material requirements, products offered by competitors, multiple use of components in the module, economic lot size, stocks – that influence the determination of the size gradation of a gear unit.

4.6 Number of motor sizes

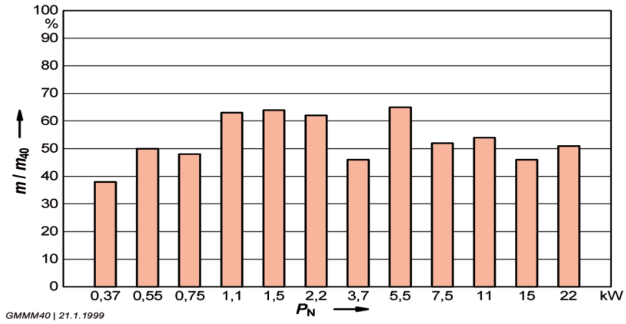
For the range between 0.18 and 22 kW, 27 motor sizes were used; the theoretical power ratio was approximately 1.2. Nowadays 22 standard sizes from 0.12 to 75 kW are used; theoretical power ratio approximately 1.34.

4.7 Weights

Materials, design of the tooth shape, machining processes and lubrication have improved to such an extent in the last six decades that it has been possible to increase considerably the specific utilisation figures for a gear unit without loss of service life and reliability. In electric motors the magnetic circuit has been optimised, the ventilation improved and the heat resistance of the insulating materials increased.
All these technological advances are reflected in a significant reduction in the weight of a geared motor, as shown in **Figure 4.7**:
The average weight of a modern geared motor is approximately 55 % of that of a geared motor in 1940.

Figure 4.7
Relative weights m/m40 of geared motors with rated outputs P_N and output speeds of approximately 100 r/min;

catalogue values for 1940 are set as 100 %



4.8 Utilisation figures

The development of the power of three-phase motors with a rated output of 15 kW in relation to weight is shown in **Figure 4.8.1**.

Figure 4.8.1
Development of the relative power p (in W/kg) of 15 kW three-phase motors (source H. D. Sprang, ETZ Volume 110 (1989), No. 11)

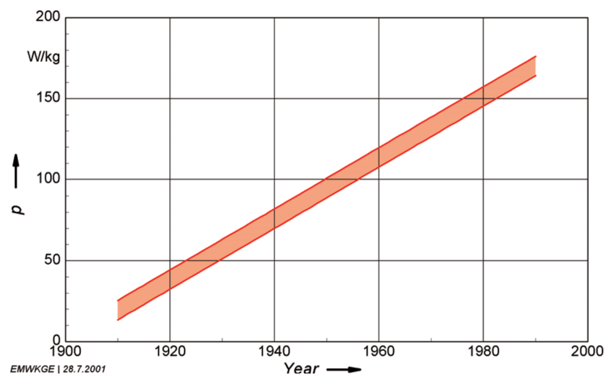


Figure 4.8.2 shows that the mass of three-phase motors of the »2000« generation is approximately 40 % that of the »1940« generation, i.e., the overall weight of geared motors found in Section 4.7 at approximately 55 % is still significantly above the trend for electric motors. In order to establish the connection with the present comparison, the weight of a three-phase motor from the year 1940 was set at 1.

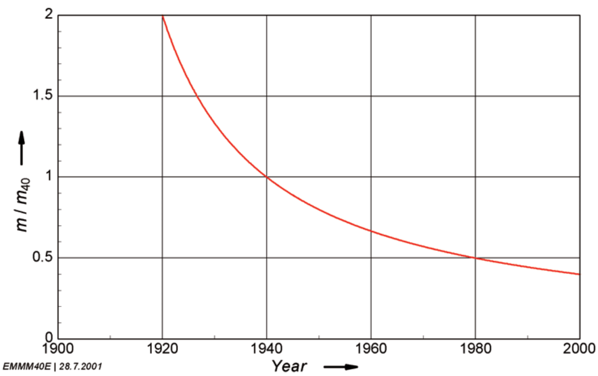


Figure 4.8.2
Development of the relative weight m / m_{40} of 15 kW three-phase motors, re-evaluated from Figure 4.8.1 and related to the year 1940

4.9 Shaft diameter

The combined effect of various influences described in the last section on the loading capacity of a gear unit cannot be transferred to an individual machine element such as the output shaft. The loading capacity of a shaft on bending and torsion is entirely dependent on the material properties and cross section. Typical shaft steels from the 1940s (e. g., St 60.11) had a tensile strength of approximately 600 N/mm², the steel used most often nowadays, C45, has a tensile strength of 580 to 770 N/mm².
Consequently the shaft diameters for transmitting certain torques could only be reduced by a relatively small amount.

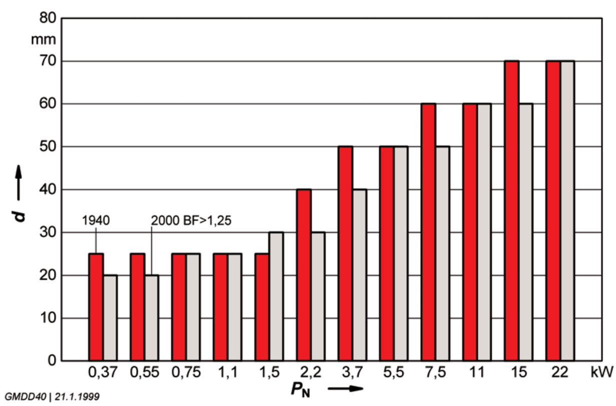
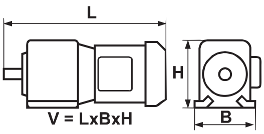


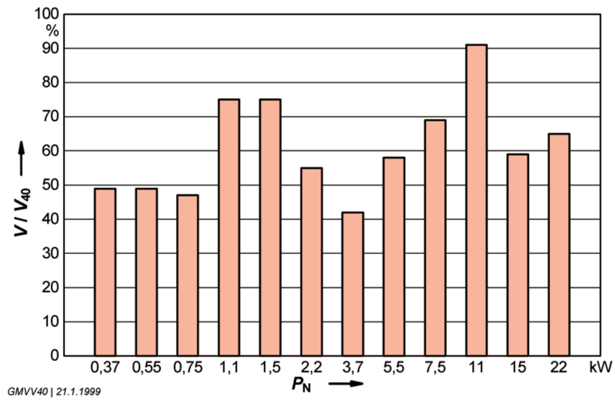
Figure 4.9
Comparison of the transmission shaft diameter *d* of geared motors of approximately 100 r/min in the catalogues for 1940 and 2000
(gear unit from the B2000 generation with a service factor of 1.25)

4.10 Envelope dimensions of the geared motor

The total space requirements for the geared motor drive unit – shown at a representative 100 r/min – have also fallen by about 40 % (**Figure 4.10**).

Figure 4.10
Dimensions of the casing of geared motors with about 100 r/min from the »2000 generation« or space requirements V; catalogue values for 1940 are set at 100 %

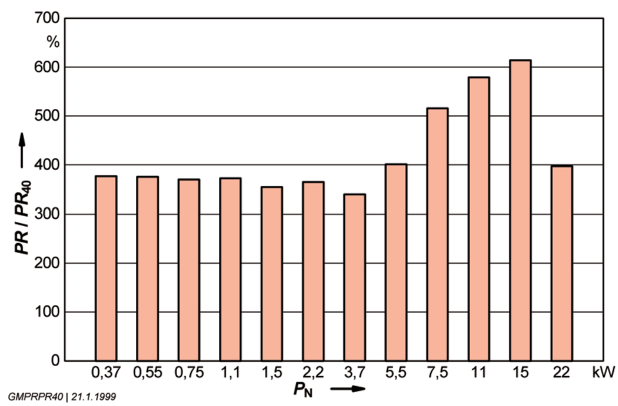




4.11 Prices

It is very difficult to compare prices for industrial products when they span a large number of years; nonetheless, an attempt will be made. In **Figure 4.11** the unweighted gross catalogue prices are compared first; they show on average a relation of about 1 : 4.2 between 1940 and 1998. This relation roughly corresponds to a buying power of 1 DM (2000) as against 1 RM (1940). As in 1940 the discount was significantly lower than it is today, it is possible to ascertain that in the 60 years that they have been included in catalogues geared motors have not become any dearer, but rather – thanks to rationalisation – they have become cheaper.

Figure 4.11
Relation between gross prices *PR* 1998/1940 for geared motors with about 100 r/min



4.12 Computer aided drive selection

With the introduction of the B2000 generation of drives the catalogue was completely redesigned; it contains all four types of gear unit, covering the following ranges:

- ☐ BG helical-geared motor
- ☐ BF shaft-mounted geared motor
- ☐ BK bevel-geared motor
- ☐ BS worm-geared motor.

Using a PC and a CD that can be obtained from the manufacture to select a drive makes it possible to search quickly and easily and to check the validity of the combination of the many modules in the modular system.
As an example, a comparison of the four types of gear unit is shown - a lengthy procedure with the conventional catalogue.

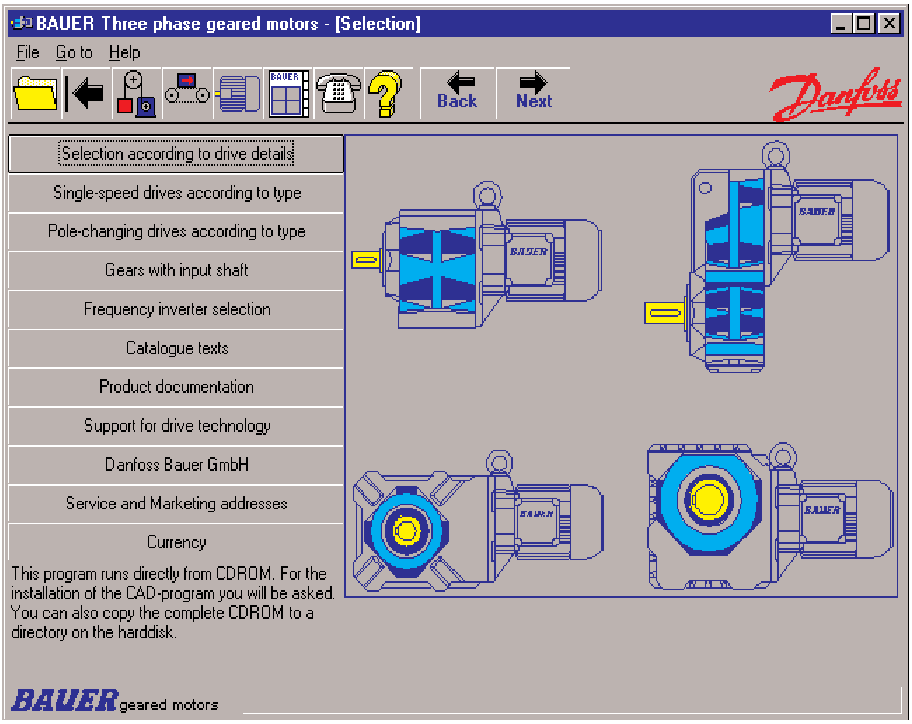


Figure 4.12.1 Start-up window for the catalogue DC

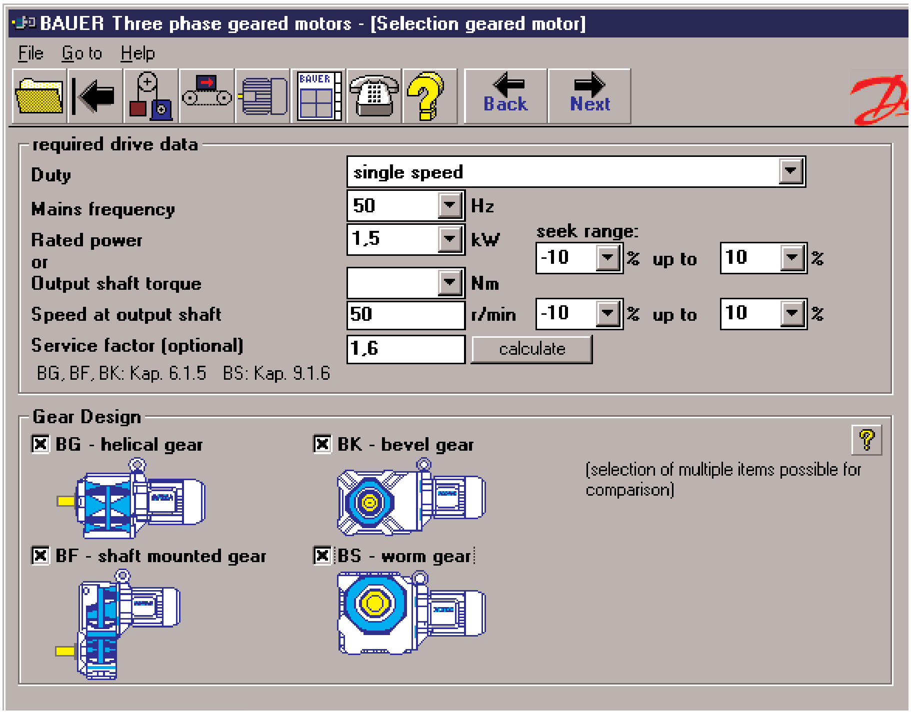
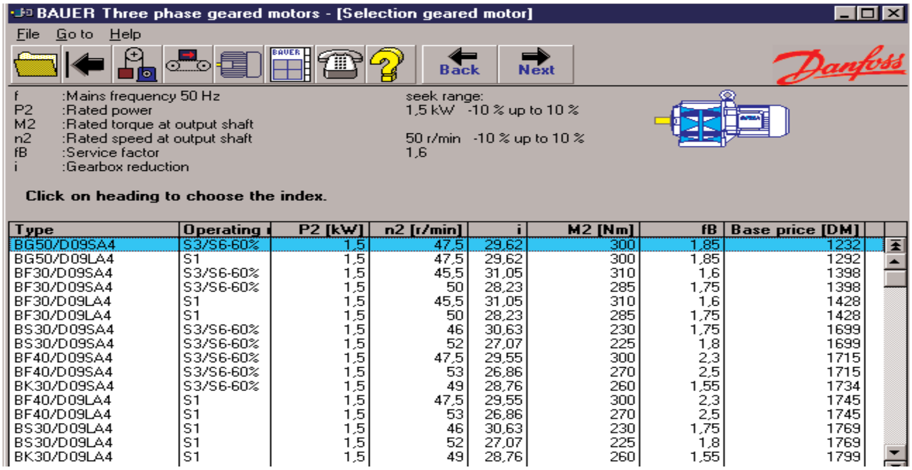


Figure 4.12.2 Entering the required drive data; here with the option of searching for solutions with all four types of gear unit



Type	Operating	P2 [kW]	n2 [r/min]	i	M2 [Nm]	fB	Base price [DM]
BG50/D09SA4	S3/S6-60%	1,5	47,5	29,62	300	1,85	1232
BG50/D09LA4	S1	1,5	47,5	29,62	300	1,85	1292
BF30/D09SA4	S3/S6-60%	1,5	45,5	31,05	310	1,6	1398
BF30/D09SA4	S3/S6-60%	1,5	50	28,23	285	1,75	1398
BF30/D09LA4	S1	1,5	45,5	31,05	310	1,6	1428
BF30/D09LA4	S1	1,5	50	28,23	285	1,75	1428
BS30/D09SA4	S3/S6-60%	1,5	46	30,63	230	1,75	1699
BS30/D09SA4	S3/S6-60%	1,5	52	27,07	225	1,8	1699
BF40/D09SA4	S3/S6-60%	1,5	47,5	29,55	300	2,3	1715
BF40/D09SA4	S3/S6-60%	1,5	53	26,86	270	2,5	1715
BK30/D09SA4	S3/S6-60%	1,5	49	28,76	260	1,55	1734
BF40/D09LA4	S1	1,5	47,5	29,55	300	2,3	1745
BF40/D09LA4	S1	1,5	53	26,86	270	2,5	1745
BS30/D09LA4	S1	1,5	46	30,63	230	1,75	1769
BS30/D09LA4	S1	1,5	52	27,07	225	1,8	1769
BK30/D09LA4	S1	1,5	49	28,76	260	1,55	1799

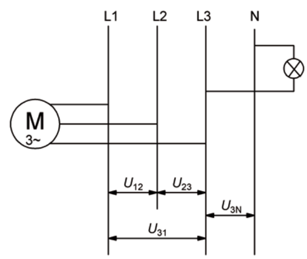
Figure 4.12.3 Results window with a selection of solutions corresponding to the required data. By clicking at the top of the column the information can be arranged according to various criteria, in this case according to basic price.

II ELECTRICAL PROPERTIES OF CAGE MOTORS

5 Rated voltage

Usually three-phase systems with three phase conductors (main conductors) L1, L2, L3 and a current carrying neutral conductor (star conductor) N are used to distribute and supply electricity.
A neutral conductor (N), which is also used as the protective conductor (PE = protection earth), is termed a PEN conductor (DIN VDE 0100 part 200). A three-phase supply, in which such a combined (C = combined) neutral and protective conductor is used, is termed a TN-C system (T = terre). Most industrial drives are connected to the three phase conductors using the three-phase system. However, heating, lighting and small domestic motors are usually connected to an phase conductor and the neutral conductor or they are connected between two main conductors, depending on the type of supply. In both cases, they are connected to a single-phase supply.
Power supply systems in Europe, Asia, Africa and Australia are dominated by a supply frequency of 50 Hz. In the following countries 60 Hz systems are used exclusively, mainly or to some extent:

Bahamas	El Salvador	Columbia	Puerto Rico
Bahrain	Guam	Korea	Saudi-
Belize	Guatemala	Liberia	Arabia
Brazil	Guyana	Mexico	Surinam
Costa Rica	Haiti	Nicaragua	Taiwan
Dominican	Honduras	Panama	Trinidad
Republic	Japan	Peru	USA
Ecuador	Canada	Philippines	Venezuela



5.1 Standard mains voltages

The values given in brackets should no longer be used after 2003 (see Section 5.2).

5.1.1 Germany

Between two phase conductors	Between phase conductors and neutral conductors
$U_m = U_{12} = U_{23} = U_{31}$	$U_{mN} = U_{1N} = U_{2N} = U_{3N}$
(380 V)	(220 V)
400 V	230 V
500 V	
(660 V)	
690 V	

5.1.2 Great Britain, Australia, India:

400 V	230 V
(415 V)	(240 V)
(420 V)	
(440 V)	

5.1.3 North America (frequency 60 Hz)

North America	System rated voltage	Rated voltage (operating voltage) of the motor Actual	Formerly
USA	120 V (1 ph)	115 V (1 ph)	110 V (1 ph)
	208 V	200 V	190 V
	240 V	230 V	220 V
	480 V	460 V	440 V
Canada	600 V	575 V	550 V

The designations used in North America are confusing because often two or sometimes even three different voltages are used for the same system. The centre column is to be used for motor name plates (in accordance with NEMA MG 10).
The terms 120/208 V, 240/416 V, 277/480 V and 347/600 V also present problems for motor manufacturers. These do not mean that there are two different 3-phase supplies, but rather that a three-phase supply of 480 V is available with a voltage of 277 V against the neutral conductor.
Therefore it is not necessary to make the winding reversible for 277 V Δ /480 V Y, for example.
The easiest and safest way of making matters clear is if motors are ordered for three-phase voltage, e. g. for 460 V and then labelled as such on the rating plate.
Three-phase supplies of 208 V are typical for larger consumers in urban areas (e. g. for the air conditioning system in an office building). NEMA recommends a motor rated voltage of 200 V for these supplies.

5.2 World standard voltage in accordance with IEC 60038

Efforts to establish a world-wide standard voltage reached a preliminary conclusion in 1983 with IEC 38. The identical German national standard DIN IEC 38 appeared in 1987. The standard voltages used for 50 Hz supplies, i.e. 380, 415, 420 and 440 V, will be replaced by one standard voltage of 400 V over a transitional period estimated at 20 years. The corresponding value would then be 230 V for single-phase supplies.

5.2.1 Standard for the systems

The new rated values should be adopted by 2003. In fact, CENELEC Memorandum No. 14 recommended that the new rated voltages be introduced by 1993. However, because Great Britain (voltages of 415, 420 and 440 V) did not formally agree to this until 1993 and only began the process of conversion to the amendments made to the »Wire regulations«, BS 7671, introduced at the end of 1994, it has not been possible to achieve the actual goal of a world standard voltage at 50 Hz. A tolerance of
+ 6/ - 10 % will be applicable for the mains voltage until 2003; after this, a tolerance of ± 10 % will be applicable. A new deadline 2008 is currently under consideration.

5.2.2 Significance of a voltage specification of 230 V

According to information from VDEW, three-phase supplies of 3 x 220 V are no longer found in the old German federal states. There are still a few 3 x 220 V three-phase supplies in the territory of the former German Democratic Republic; these will be converted to 3 x 400 V as soon as possible.
The 230 V voltage is nearly always a **single-phase** voltage for lighting and control mains. Therefore, a voltage specification of 230/400 V can be assumed to identify a supply system having 1~ 230 V / 3~ 400 V. The designation 230/400 V Δ/Y
(i.e. 3~ 230 / 3~ 400 V Δ/Y) makes no sense for ordering and labelling motors supplied by the mains and should therefore be avoided. Only inverter-fed motors may be 3 x 230 V rated.

5.2.3 Acceptance of the “Euro voltage” in European countries

In spite of the ***CENELEC Memorandum***, practical acceptance of the “Euro voltage” is generally found to be unsatisfactory, even though we are nearly at the end of the transitional period. This applies in particular to Great Britain whose special supply of 415 or 420 V was an important factor for the introduction of the new 400 V voltage.
The survey as shown in **Figure 5.2.3** does not make clear the proportion of motors to be used in the country concerned (i.e. at the »standardised« 400 V) and what proportion is intended for export to countries where the 380 V standard is still used.

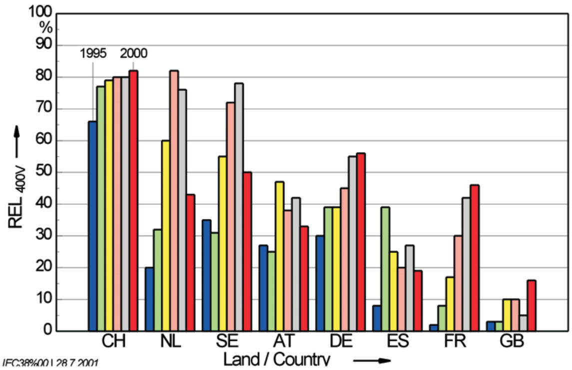


Figure 5.2.3
Acceptance REL_{400V} of the 400 V »Euro voltage« in eight European countries according to the Danfoss Bauer delivery statistics 1995 ... 2000

5.3 Permissible voltage variations for electrical machines

EN 60034-1/VDE 0530 Part 1, which has been harmonised with IEC 60034-1, still applies to electrical machines. Subclause 12.3 of this standard specifies a permissible voltage fluctuation of ± 5 %. This tolerance is based on the voltage specified on the rating plate, i.e. a motor which is rated for

380 V can be used for voltages	361 to 399 V
400 V	380 to 420 V.

The standardised tolerance of ± 5 % is not specified on the rating plate (cf. DIN VDE 0530-1, subclause 12.3). In contrast to the specifications for the system voltage and tolerance of many other apparatus, electrical machines allow a relatively tight supply voltage tolerance band. This is based on the following technical grounds: Small motors (e. g. below approximately 1.1 kW) and low-speed motors often operate near to the magnetic saturation and are relatively sensitive to overvoltage. If the motor is being operated under voltage fluctuations which exceed the ± 5 % currently standardised, IEC 60034-1 specifies that the motors must be capable of performing their primary function: They can deliver their rated torque. In this case, the usual characteristics (and the heating as well, for example) may exhibit greater deviation from the data specified for the rated voltage.

	ΔU in %	
	10	**Range B** The motor must be capable of performing its primary function and must not exhibit significant deviations from the ratings; extended operation at the limits of range B is not recommended; not permissible for EEx
	5	
Nominal working point or rated point	0	**Range A** The motor must be capable of performing its primary function in continuous running duty The degree of heating may be 10 K higher than the limit value; also permissible for EEx
	- 5	
	- 10	**Range B** The motor must be capable of performing its primary function and must not exhibit significant deviations from the ratings; extended operation at the limits of range B ist not recommended; not permissible for EEx

Table 5.3.1 Permissible voltage fluctuations for motors in accordance with DIN VDE 0530-1 and IEC 60034-1, Figure 14

Tolerance range B represents a concession for **normal, non explosion-proof** machines which manufacturers and operators may use at their own risk after weighing up the effects on the operating data and service life of the winding insulation. Because safety is affected in the case of **explosion-proof** motors, the conversion to a 400 V supply must be performed and documented in compliance with the relevant standards (e. g. EN 50018 and EN 50019) and the specific motor design.

5.4 Windings for a range of the rated voltage

The unsatisfactory introduction of the 400 V “World standard voltage” has led to an unforeseen consequence: Motors with **varying-voltage winding** or **multiple rated voltages** such as 380 ... 400 V or even 380 ... 420 V.

5.4.1 Necessity of voltage ranges

Countries which are not subject to the CENELEC agreement, will remain with a voltage of 380 V for an unspecified time. This includes all the countries of former Eastern Europe. In fact, the old voltage of 380 V will also prevail in the Eastern states of Germany until the transitional period expires in 2003.
Export-oriented equipment manufacturers who stock up on electric motors and motor manufacturers who wish to produce their windings in economic batch sizes, therefore have to plan **three** instead of **two** winding designs: 380, 400 and 415 V.
Machine factories and motor manufacturers have therefore been looking for solutions using **varying-voltage windings**, e. g. 380 ... 400 V or even 380 ... 420 V.

5.4.2 Notation for a voltage range

The standard format for indicating a voltage range is 380 ... 400 V, for example.
A forward slash should only be used to indicate a **dual-voltage winding**, e. g.

Tap changing	220 / 380 V
Speed (pole) changing	1420/2840 r/min (in case of dual-speed winding)

5.4.3 Tolerance on the voltage range

How do you read a motor rating plate with a varying-voltage winding? Is 380 ... 420 V simply another way of writing 400 V ± 5 %? The standards and competent commentaries clearly state that this is not the case. The normal tolerance of ± 5 % applies both for the single specification of a rated voltage (e. g. 400 V) and for a voltage range specification.

5.4.3.1 Voltage tolerance ratings on electrical machines
The following examples are based on
- ☐ EN 60034-1 = DIN VDE 0530-1 (1995)
- ☐ Explanations on DIN VDE 0530, VDE publication 10 (1993)
- ☐ Confirmation from 18.02.1991 by the representative of the K 311 committee responsible for VDE 0530.

5.4.3.1 Voltage tolerance ratings on electrical machines

Specified rated voltage		B rated voltage range	Implicitly standardised	Limits of range A in accordance with, IEC 60034-1, subsection 12.3	
Fixed	Addition		Tolerance	U_{min}	U_{max}
400 V	-	-	± 5 %	380 V	420 V
400 V	IEC 38	360 ... 440 V	± 5 %	342 V	462 V
400 V	± 10 %	360 ... 440 V	± 5 %	342 V	462 V
-	-	380 ... 420 V	± 5 %	361 V	441 V

5.4.3.2 Indication of a tolerance deviating from ± 5 %
There are different ways of indicating a voltage tolerance which deviates from the standard (e. g. ± 6 % in accordance with the old British standards). In cases of doubt a clear arrangement between the manufacturer and the operator is recommended.

☐ In accordance with IEC 60034-1 and K 311:

Plate	Implicit tolerance	Total tolerance
400 ± 1 %	± 5 %	± 6 %

☐ In accordance with PTB test regulation (1969), subsection 5.7.1, and the practice of many manufacturers:

Plate	Total tolerance
400 ± 6 %	± 6 %

5.4.3.3 Consequences of the tolerance rating
A motor with the rating 380 ... 420 V must maintain the temperature rise limit in accordance with its temperature class for any voltage between 380 and 420 V and must also develop a breakdown torque at a voltage of 380 V which is at least 160 % of the rated torque. Furthermore it must be capable of performing its primary function at 380 V - 5 % = 361 V and at 420 V + 5 % = 441 V (even if this involves an additional temperature rise of around 10 K). It must still be able to develop its rated torque at 380 V – 10 % = 342 V (i.e. the lower limit of range B in accordance with Table 5.3.1). It is not easy for small machines to fulfil this requirement.

5.5 Limits and risks of a large voltage range

Section 5.6 shows that relatively small machines are sensitive to overvoltage and can become relatively warm at the limits of the normal voltage tolerance even when they are operating at no load. The basic principle applies that the starting torque and break-down torque vary proportionally to the square of the voltage applied – irrespective of the torque requirement or level of utilisation.
The risks involved in applying a »wide voltage range« are shown in the following three examples:

☐ Small motor (e. g. manufactured in the UK, used in Eastern countries):
Plate rating: 380 ... 420 V
Assumption: at 420 V $M_K/M_N = 1.6$
at 361 V $M_K/M_N = 1{,}6(361/420)^2 = 1{,}18$

The motor is so »gentle« that a slip of between 20 and 30 % is to be expected at nominal torque. This quickly reaches 100 % when there is a heat build-up – the motor will »breakdown« and will no longer be capable of performing its primary function.

☐ Large motor (e. g. manufactured in Germany, used in the UK):
Plate rating: 380 ... 420 V
Assumption: at 380 V $M_K/M_N = 3.0$
at 441 V $M_K/M_N = 3.0\ (441/380)^2 = 4.0$

These kinds of high breakaway and starting torque make demands on the mechanical power transmission components.
The inevitably high current density in locked rotor conditions represents a thermal risk on the winding when the motor is stalled.

☐ Any size of motor:
Plate rating 400 ± 10 % or IEC 38
Fluctuation extent of M_A and M_K in range A: $(462/342)^2 = 1.82$!
e. g. $M_K/M_N = 1.6\ ...\ 2.9$
or $M_K/M_N = 0.9\ ...\ 1.6$

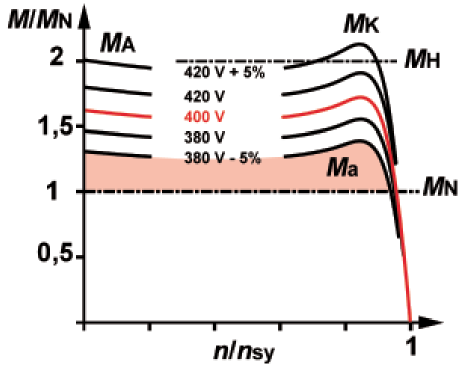
It is very difficult or impossible to adapt the torque optimally in accordance with the specific use.

Figure 5.5 shows the torque-speed-characteristic curves for a motor designated with »380 ... 420 V«. The shaded area represents the acceleration, i.e. for the starting time reciprocal value. This can vary at the limits of the voltage tolerance range with the same load proportions by a ratio of 1 : 3 (i.e. by 0.5 to 1.5 seconds, for example).

It is, after all, improbable that a particular motor with this fluctuation extent would be exposed to the voltage. Models with large voltage ranges suggest to the manufacturer and the operator of a machine that the same drive motor will behave in the same way in very varied voltage conditions (i.e. in the UK and Russia, for example). ***For physical reasons, this expectation cannot of course be fulfilled.***

Figure 5.5
Torque-speed characteristic curves for a cage motor designed for 400 V and designated for 380 ... 420 V at different voltages in the entire tolerance range.

The shaded area represents the acceleration when the load conditions remain the same.



Motors for large voltage ranges are nearly always compromises – unless the active material use (i.e. the model size) is increased with respect to the standard design.

5.6 Performance characteristics under voltage variation

A test series can be used to assess the performance characteristics of three-phase asynchronous motors under variation of the supply voltage. This is often performed as part of the type test to fine-tune the winding design: Constant output at different voltages. Fundamentally, the type test is used to determine the ***magnetic flux density (induction)*** which gives the best performance characteristics. The winding is then designed for mass production such that the most favourable flux density is achieved when the motor is operated at the rated voltage. If at all possible, the flux density should be selected such that the least losses are experienced at the rated voltage. In this arrangement, motor heating is kept to a minimum at the rated output (hereafter termed the optimum flux density).
However, there are compelling reasons for selecting a flux density that is lower or higher than the optimum flux density.

Diagrams 5.6.1 to **5.6.3** must be viewed as purely qualitative. The trend should be perfectly clear from a simplified and exaggerated presentation. This does not lend itself to quantitative analysis.

- ☐ The ***active current*** I_w which contributes to the mechanical output exhibits a falling trend (because of the slip decreasing, etc.) as the voltage (flux density) increases.
- ☐ The ***magnetising current*** I_μ which forms the magnetic flux exhibits a rising trend as the voltage (flux density) increases. This trend is super-proportionally steep, particularly when the saturation limit is reached.
- ☐ The ***line current I*** to be measured in the supply line is composed geometrically of the components I_w and I_μ.
- ☐ The ***minimum line current I*** which also represents the losses characterises the optimum flux density.

5.6.1 Rated voltage (flux density) with the optimum flux density

This arrangement must be achieved if possible and is typical for motors with rated outputs of 1.1 ... 11 kW.

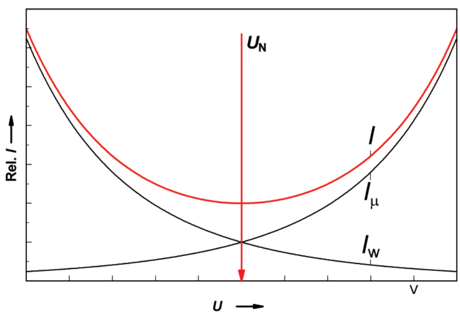


Figure 5.6.1
Current consumption trend *I* of medium-size motors (approx. 1.1 ... 11 kW) under variation of the supply voltage *U*

Rated voltage assignment U_N within the optimum flux density (qualitative representation)

Assessment of the performance characteristic:

- ☐ Voltage variations within standard tolerances have relatively little effect on the current consumption (heating).
- ☐ It is generally permissible to continue to operate a motor at the new rated voltage of 400 V.

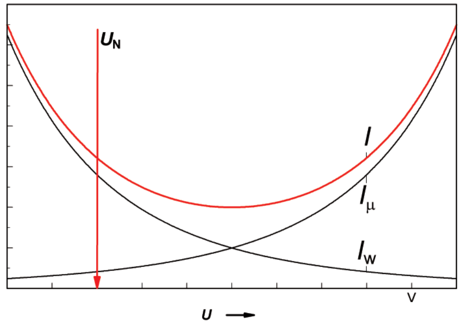
5.6.2 Rated voltage (flux density) below the optimum flux density

This arrangement is typical for motors with rated outputs above approximately 11 kW since excessive breakaway torques and starting currents would result at the optimum flux density. Although the breakaway torques only pose a danger to downstream transmission components (geared motors) and driven machinery, high locked rotor current densities lead to dangerously rapid and severe temperature increases in the event of stalling which may no longer be detected by thermistors etc.

5.6.2 Rated voltage (flux density) below the optimum flux density

Figure 5.6.2
Current consumption trend I of large motors (approximately > 11 kW) under variation of the supply voltage U

Assignment of the rated voltage U_N below the optimum flux density (qualitative representation)



Assessment of the performance characteristic:

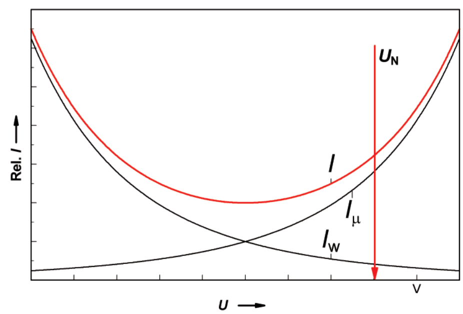
- ☐ A reduction in the voltage leads to increased current consumption (heating)
- ☐ An increase in the voltage leads to reduced current consumption (heating)
- ☐ Continued operation of a motor at the new rated voltage of 400 V is permissible if the increased M_A and M_K values are harmless for the driven machinery.

5.6.3 Rated voltage (flux density) above the optimum flux density

This critical arrangement may be required for motors with rated outputs below approximately 1.1 kW because the standardised overload capacity $M_K/M_N \geq 1.6$ would not be achieved at the optimum flux density. This is the critical group when it comes to the continued operation of 380 V motors at the 400 V mains supply.

Figure 5.6.3
Current consumption trend I of small motors (approximately < 1.1 kW) under variation of the supply voltage U

Rated voltage assignment U_N above the optimum flux density (qualitative representation)



Assessment of the performance characteristic:

- ☐ A reduction in the voltage leads to reduced current consumption, but this jeopardises the overload capacity $M_K/M_N \geq 1.6$ as required by the standard.
- ☐ An increase in the voltage leads to (much) greater current consumption (heating) due to saturation. The no-load current is often greater than the rated current!
- ☐ The ability to continue to operate a motor at the new rated voltage of 400 V is generally uncertain. Check the current consumption and heat build-up in actual operation and consult the manufacturer.

5.7 Power factor as indication for the optimum flux density

The procedure in 5.6 presupposes the measurements under nominal load which are generally carried out by the manufacturer during the course of development. A judgement whether a motor can continue to be used at the new 400 V supply means that it is necessary to consult the manufacturer. Therefore a method which provides an immediate assessment by reading the rating plate data is desirable. The power factor states where the magnetic flux density (induction) in the rated point is located in relation to the optimum flux density:

Low power factor ⇨ higher reactive current ⇨ above optimum flux density
High power factor ⇨ lower reactive current ⇨ below optimum flux density

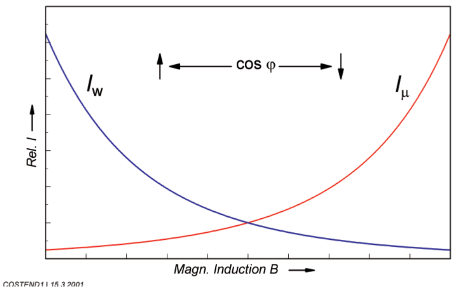


Figure 5.7
Power factor as indication for the optimum flux density

The following conclusions can be drawn from the comparison with Section 5.6:

- ☐ ***For motors with a power factor > 0.85 the rated voltage is below the optimum flux density***
- ☐ ***For motors with a power factor between 0.7 and 0.85 the rated voltage is close to the optimum flux density***
- ☐ ***For motors with a power factor < 0.7 the rated voltage is above the optimum flux density***

5.8 Recommendation to continue to operate a motor at 400 V

The following recommendations apply to

- ☐ Three-phase induction motors wound for 380 V, 50 Hz.
- ☐ Standard arrangement, e. g. models from the catalogue.
- ☐ Without explosion protection
- ☐ Duty type S1 close to or at the rated output.

These may be used in certain individual cases, but the operator must assume entire responsibility.

For small three-phase motors (below approximately 1.1 kW and/or with a power factor < 0.7) the current consumption may increase above the rated current even at low loads, depending on the arrangement. A motor protection switch may trigger and report a danger if it was not set cautiously higher so that operation may continue. In this motor group a higher winding temperature is generally set. This may lead to a reduced service life depending on the thermal reserves.

You are recommended to check small three-phase motors and their motor protection switches and to wind them to the new rated voltage of 400 V as a precaution, if necessary.
You are recommended to rate the winding of all motors (for medium and large power ratings) to 400 V if a new winding is required for other reasons.

However, if ***explosion-proof motors*** are affected, adapting to the new voltage is not a matter of discretion: These motors must be adapted to the new mains voltage irrespective of the size and utilisation (possibly by consulting an ***authorised inspector*** specialized in the field of explosion protection).
Whether or not rewinding is necessary, must be decided on a case-by-case basis (see the SD 300 special imprint).

5.9 Designation of the power supply

A (three-phase) 400 V supply system between the phase conductors and 230 V (single-phase) between the phase conductor and neutral conductor is denoted as
3/PEN ~ 400 V or 3/PEN AC 400 V in accordance with DIN 40004.

Other clear designations include:
Three-phase 400 V or 3 x 400 V or 3 x 400 V / 1 x 230 V or
400 V 3 ~ / 230 V 1N ~.

The availability of a 230 V single-phase voltage is irrelevant to the specification of a three-phase motor.
It is not only unnecessary but also misleading to describe such systems as 230/400 V or 400/230 V.

Further examples of power supply designations in accordance with DIN 40004 (1983):

Description in words	Abbreviated form with graphic symbol	Abbreviated form with short designation
Direct current 220 V	= 220 V	DC 220 V
Alternating current 230 V	~ 230 V	AC 230 V
Direct or alternating current	250 V	UC 250 V
0 to 440 V variable direct-current voltage	= 0 ... 440 V	DC 0 ... 440 V
Single-phase 2-wire system with two 220 V phase conductors	2 ~ 220 V	2 AC 220 V
Single-phase 3-wire system with 1 phase conductor, 1 neutral conductor and 1 protective conductor 230 V	1/N/PE ~ 230 V	1/N/PE AC 230
Single-phase 3-wire system with 2 phase conductors and 1 neutral conductor 220 V, 50 Hz	2/N ~ 50 Hz 220 V	2/N AC 50 Hz 220 V
245 kV three-phase 3-wire system	3 ~ 245 kV	3 AC 245 kV
380 V three-phase 4-wire system with combined neutral and earth protection conductor	3/PEN ~ 380 V	3/PEN AC 380 V
400 V three-phase 5-wire system with separate neutral and earth protection conductor	3/N/PE ~ 400 V	3/N/PE AC 400 V
Note: The oblique strokes between the conductor information may be omitted		

5.10 Motors for two mains voltages

5.10.1 The 220 V system is no longer used

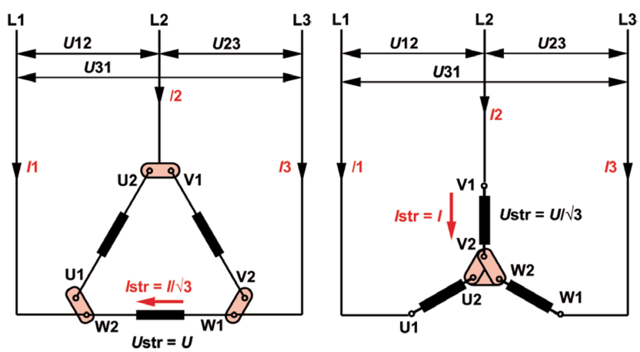
All voltage systems in the territory of former West Germany have an phase conductor voltage of 3 x 400 V.
According to information from the Association of German Power Supply Authorities (VDEW - Vereinigung Deutscher Elektrizitätswerke) about 5 % of public supply systems in the territories of former East Germany still have a voltage of 3 x 220 V.
Therefore a multi-voltage design should be planned for the few remaining motors which will first be connected to 3 x 220 V and then changed over to 3 x 400 V.
This also applies to drives used in both areas (e. g. construction machinery), which are to be used on both systems.

5.10.2 660 V designation with double significance

The demand for a multi-voltage design forces the motor manufacturer to allocate the voltage and terminal switching very clearly and therefore rules out the use of other switching types (e. g. star-delta starting or pole-changing).
Above all for small motors an increase in the terminal breadth and thereby also the terminal box is sometimes required for connection to 660 (690) V. Therefore multi-voltage three-phase motors should only be ordered for two mains voltages (e. g. 220/380 V), even if a connection to 220 or 380 V may be possible. If only one supply voltage is specified (e. g. 380 V), then only one voltage should be noted in the order.

5.10.3 Tap changing Δ/Y in the ratio 1:√3

Where three-phase motors are to be connected to two different three-phase supplies, whose voltages are between the main conductors in the ratio 1:√3 = 1 : 1.73 (e. g. 3 x 220 and 3 x 380 V), this is simply carried out by changing the terminal connections to delta or star.



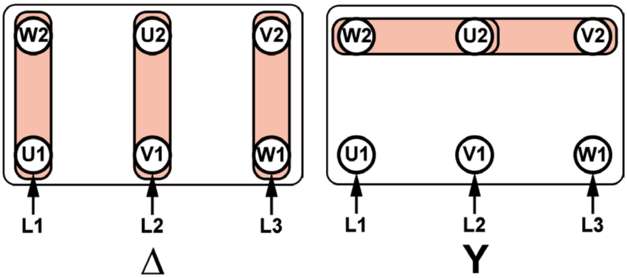


Figure 5.10.3 Terminal connections of a three-phase motor for 2 mains voltages in the ratio 1:$\sqrt{3}$ (Δ/star connection)

The voltage change on the terminal board (Δ/star connection) in the diagram above shows how the same specific load for the phase winding is achieved despite different mains voltages.
The performance characteristics and the winding temperature rise remain completely unchanged.

Delta connection:

Voltage between the line conductors $U = U_{12} = U_{23} = U_{31} = U_{\Delta}$ (e. g. 220 V)

Voltage applied to a phase winding $U_{str} = U_u = U_v = U_w = U_{\Delta}$ (e. g. 220 V)

Current in the line conductor $I = I_1 = I_2 = I_3 = I_{\Delta}$ (e. g. 17 A)

Current in phase winding $I_{str} = I_u = I_v = I_w = \frac{I_{\Delta}}{\sqrt{3}}$ (e. g. 10 A)

Output

$$P_{mec} = 3 \cdot U_{str} \cdot I_{str} \cdot \cos\varphi \cdot \eta$$

$$= 3 \cdot U_{\Delta} \cdot \frac{I_{\Delta}}{\sqrt{3}} \cdot \cos\varphi \cdot \eta$$

$$= U_{\Delta} \cdot I_{\Delta} \cdot \sqrt{3} \cdot \cos\varphi \cdot \eta$$

Star connection:

Voltage between the line conductors	$U = U_{12} = U_{23} = U_{31} = U_Y$	(e. g. 380 V)
Voltage applied to a phase winding	$U_{str} = U_u = U_v = U_w = \frac{U_Y}{\sqrt{3}}$	(e. g. 220 V)
Current in the line conductor	$I = I_1 = I_2 = I_3 = I_Y$	(e. g. 10 A)
Current in phase winding	$I_{str} = I_1 = I_2 = I_3 = I_Y$	(e. g. 10 A)

Output

$$P_{mec} = 3 \cdot U_{str} \cdot I_{str} \cdot \cos\varphi \cdot \eta$$

$$= 3 \cdot \frac{U_Y}{\sqrt{3}} \cdot I_Y \cdot \cos\varphi \cdot \eta$$

$$= U_Y \cdot I_Y \cdot \sqrt{3} \cdot \cos\varphi \cdot \eta$$

Relative current in the main conductor $\frac{I_Y}{I_\Delta} = \frac{U_\Delta}{U_Y}$

5.10.4 Tap changing ΔΔ/Δ in the ratio 1: 2

There are areas in the USA where there are three-phase supplies of 3 x 220 V and 3 x 440 V, which were changed some time ago to 230 and 460 V. The three-phase motors must be connected to a 9-pin terminal board through a special connection (parallel and series switching) for both these rated voltages (see Section 18).

6 Rated output

In most electric motor drives the total power required after running up to speed generally consists of the following two main components (see **Figure 6.2**).
The dynamic torque requirements (e. g. for starting or for acceleration) must be considered separately.

6.1 Hoisting power

$$P_H = \frac{m \cdot g \cdot v_{vert}}{\eta \cdot 1000}$$

6.2 Friction power

$$P_R = \frac{F_R \cdot v}{1000}$$

$$F_{R1} = \mu \cdot m \cdot g$$

$$F_R = F_{R1} + F_{R2} + F_{R3}$$

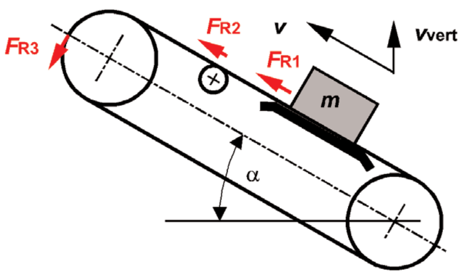


Figure 6.2
Schematic diagram for the determination of the power of an electric drive

P – Power in kW
F_R – Friction resistance in N
m – Mass (weight) in kg
g – Acceleration of free fall (9.81 m/s²)
v – Velocity in m/s
η – Efficiency of outer transfer as adecimal fraction
μ – Coefficient of friction
Index H: Hoisting
Index R: Friction
Index vert: In vertical direction

In the determination of a drive's power rating, the power required for acceleration may be ignored, provided starting is not too frequent and the run-up time is normal. Since almost all electric motors develop about twice the rated torque during starting, they can supply additional torque for acceleration over their rated output (= continuous rating) for short periods. As a general rule one can calculate:

6.3 Total power rating of the drive

$$P = P_H + P_R$$

6.4 Determination of nominal rating

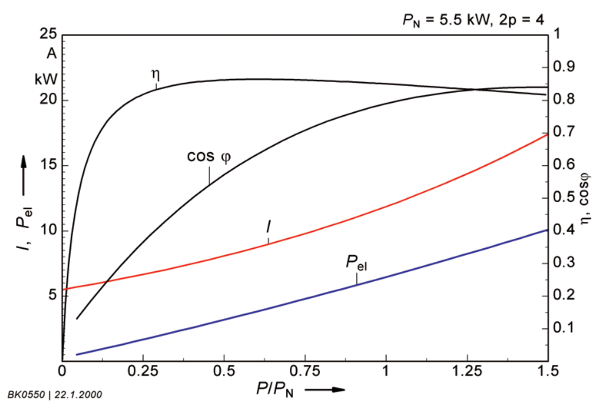
Whenever possible, the nominal rating of drives should be fixed not only by calculation, but by considering similar applications or taking measurements on completed equipment. If the actual power requirement is appreciably smaller than the nominal rating of the motor, the excess accelerating power will lead to a very rapid, possibly shock-like, run-up. In operation, the very lightly loaded motor will also have poor power factor and efficiency (see **Figure 6.4.1** and **6.4.2**).
If, on the other hand, the actual power requirement is larger than the rated power of the motor, inadequate accelerating torque will result in the run-up being sluggish or the motor not running up to speed at all. Under operating conditions, this will cause the windings to overheat and, unless there is thermal protection, the motor may burn out (see section 39). In the case of three-phase asynchronous motors, the actual power output can be determined by simple electrical measurements:

$$P_{mec} = \frac{\sqrt{3} \cdot U \cdot I \cdot \cos\varphi \cdot \eta}{1000}$$

P_{mec} – Mechanical power output in kW
U – Supply voltage, measured between two phase conductors in V
I – Power consumption in each line under load, in A
$\cos\varphi$ – Power factor depending on motor size and loading in accordance with data supplied by the motor manufacturer, see **Figure 6.4.2** for typical values
η – Efficiency depending on motor size and loading in accordance with data supplied by the motor manufacturer, see **Figure 6.4.3** for typical values.

For normal production motors, the manufacturer has at his disposal ***load characteristics*** from the type test (see Figure 6.4.1), which allow for simple and reliable power rating determination when used in conjunction with section 38.

Figure 6.4.1
Load characteristics of a three-phase motor, from the manufacturer‘s type test



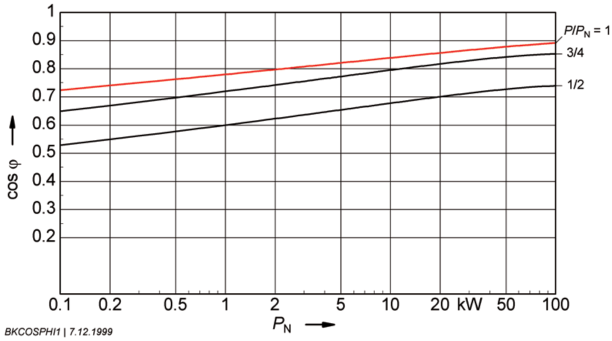


Figure 6.4.2
Typical values of the power factor for standard 4-pole geared motors at various rated outputs P_N

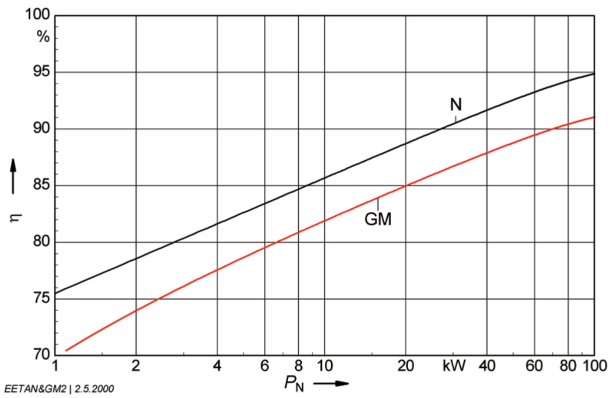


Figure 6.4.3
Efficiency η of 4-pole standard motors (N) compared with the overall level of efficiency of geared motors (GM), using »oil-tight« motors and 2-phase helical-gear units

If the power required is principally determined by either friction or lift, a torque measurement using a spring balance is the answer. During measurement, the motion should be kept as uniform as possible so as to avoid the inclusion of any acceleration component.
When making measurements on electric motors, it should be noted that intermittent torque peaks can usually be covered by the kinetic energy stored in the rotor, and thus have little effect on the power drawn from the supply. The electrical values measured (current and power consumption) are thus at all times a measure of the thermal loading on the motor, but may not always be indicative of the mechanical loading on the reduction gearing.

7 Rated current

Often as early as the project stage (e. g., for dimensioning the conductor cross section) guide values are needed for the currents of three-phase motors. The rated currents for a standard design can be found in the appropriate catalogues.
As rough guide values for single-speed three-phase motors and for motors with two speeds 1:2 in Dahlander connection it is possible to use the values shown in **Figure 7.1**, and in the case of pole-changing with dual-wound stators the values shown in **Figure 7.2**.
These guide values are not suitable for the selection and adjustment of motor protection switches.

Fig 7.1
Guide values for the rated current I_N of three-phase motors with one speed or with two speeds at a ratio of 1:2 (Dahlander connection) at 400 V

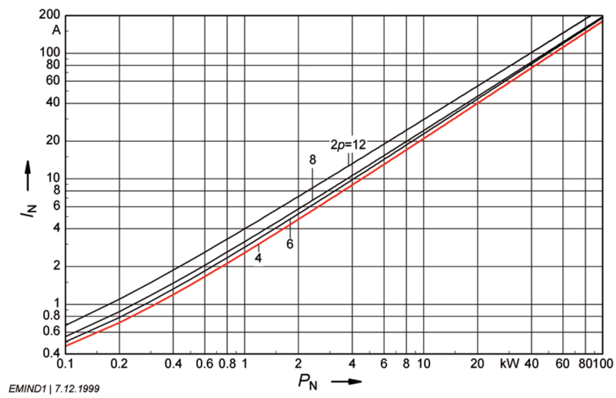
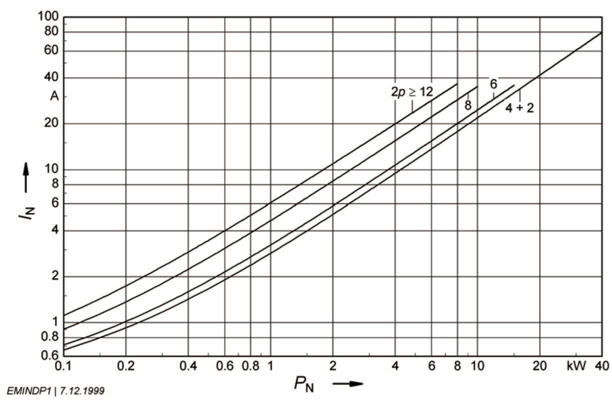


Figure 7.2
Guide values for the rated current I_N of pole-changing dual-wound three-phase motors with windings at 400 V



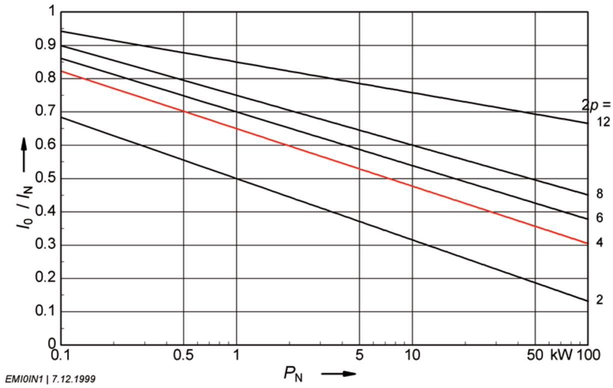


Figure 7.3 Guide values for the relative no-load current I_0 / I_N of three-phase motors with one speed

8 Rated speed

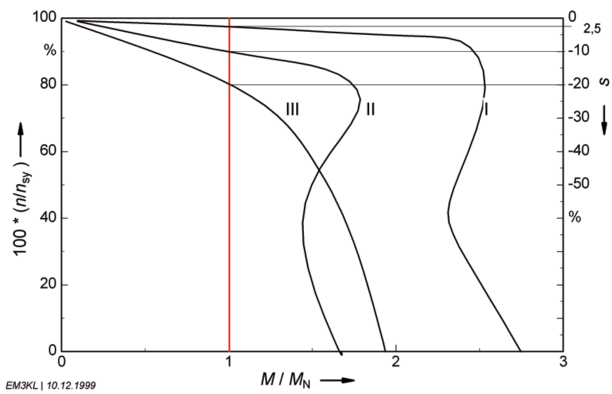
8.1 Asynchronous motors with cage rotors

As the load is increased, the actual speed *n* of an induction motor falls from its initial no-load speed n_0, which is effectively the synchronous speed nsy described in section 1.1. The ***slip*** in % is defined as

$$s = \frac{n_{sy} - n}{n_{sy}} \cdot 100$$

Three-phase induction motors of normal design have, when at rated full load torque M_N, a rated-load slip s_N which for smaller motors (about 0.11 kW) will be approximately 12 %, and for larger motors (about 75 kW) will be approximately 2 %. Their torque/speed relationships have a shunt characteristic, as shown in **Figure 8.1**.

Figure 8.1
M/n – Characteristics:
Slip *s* and speed *n* shown against the proportion of full load torque M/M_N for
I Cage motor Rated output 75 kW
II Cage motor Rated output 0.37 kW
III High-slip motor Series DL



In addition to the factors affecting rated speed due to the various types of construction, different designs and rated powers, EN 60034-1/IEC 60034-1 permits a tolerance of ± 20 % on the rated full load slip for machines of the same nominal specification.
A practical example with an assumed gear reduction of $i = 30$ could therefore have the following estimated speeds in r/min:

	Motor shaft	Output shaft
Synchronous speed (approx. the same as the no-load speed)	1500	50
Rated speed	1330	44,33
Slip	170	5,67
Tolerance on the slip	±34	±1,13
Permissible maximum rated speed	1364	45,46
Permissible minimum rated speed	1296	43,20

With the standard tolerances, the output shaft can thus have a speed range from no-load to full load of between 50 and 43,2 r/min.
Two drives of the same series and at exactly the same loading - which seldom occurs in practice - could, with maximum tolerable differences in the slip, have full load speeds of 43,2 and 45.5 r/min.
Although the standard tolerances are not generally incurred, the example shows that where there are precise requirements for constant or matched speeds, the advice of the manufacturer should be sought at an early stage in the project.

8.2 Rated-load slip

Typical slip values for standard 4-pole cage motor rated loads can be found in **Figure 8.2**.

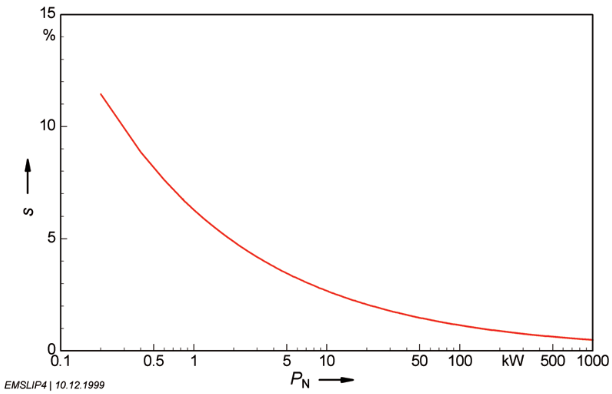


Figure 8.2
Typical values for the rated-load slip of 4-pole cage motors

8.3 High-slip induction motors

In some cases a particularly “soft” speed characteristic, and hence a higher amount of slip, is desirable. The DL type series has been found satisfactory for many years for such types of duty, especially for crane hoist and crab drives. Its torque/speed characteristic is shown for comparison as curve III in Figure 8.1. Such motors are not suitable for speed control by frequency (inverter control), see also section 46.

9 Efficiency

In accordance with a voluntary agreement between the directorate-general DG XVII of the European Commission and ***CEMEP*** (European Committee of Manufacturers of Electrical Machines and Power Electronics) the levels of efficiency of 4- and 2pole standard motors in the power range of 1.1 ... 90 kW are classified and indicated in catalogues and on rating plates with a specially developed logo. The agreement currently applies to three-phase cage induction motors with the following characteristics:

Power range	1.1 ... 90 kW
Degree of protection	IP54 or IP55
Number of poles	2 or 4
Duty type	S1
Rated values	400 V / 50 Hz.

The following designs are listed amongst others as being ***outside the scope of the agreement***:

- ☐ Motors for special ambient conditions
- ☐ Motors with adjustable speeds, with or without frequency inverters
- ☐ Motors with integrated brakes
- ☐ Non-ventilated motors (IC410)
- ☐ Motors with special cooling types (e. g. IC416, 417, 418 or with heat exchangers)
- ☐ **Geared motors of an integral construction**
- ☐ Stator – rotor components
- ☐ Explosion-proof motors
- ☐ Encapsulated motors.

9.1 Classification of levels of efficiency

Three classes of efficiency levels are defined; these must be specified in the documentation and on the rating plate. **Figure 9.1** shows the classes for 4pole induction motors in the form of a graph; the tables in Appendix 1 of the agreement apply to individual cases.

Class	Description of the level	Abbreviation	Protected logo	Example for 4 poles at 11 kW
1	High	EFF1	EFF 1	$\eta \geq 91$ %
2	Improved	EFF2	EFF 2	$\eta \geq 88,4$ %
3	Normal (average)	EFF3	EFF 3	$\eta < 88,4$ %

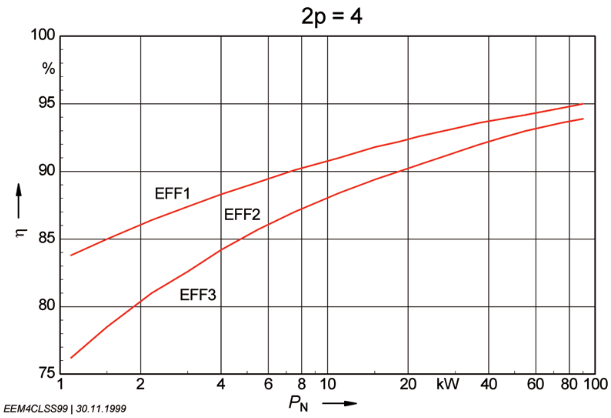


Fig 9.1
Efficiency level classes of 4pole three-phase motors
EFF1 – high
EFF2 – improved
EFF3 – normal

9.2 Dependence between motor size and utilisation

Fig 9.2 shows the efficiencies of 4pole three-phase motors with rated outputs of 1.5 kW, 15 kW and 132 kW as a function of the relative loading P/P_N. This comparison indicates two important influences:

- ☐ ***The efficiency at the rated point increases as the rated output increases***
- ☐ ***The efficiency remains virtually constant under partial load and overload.***

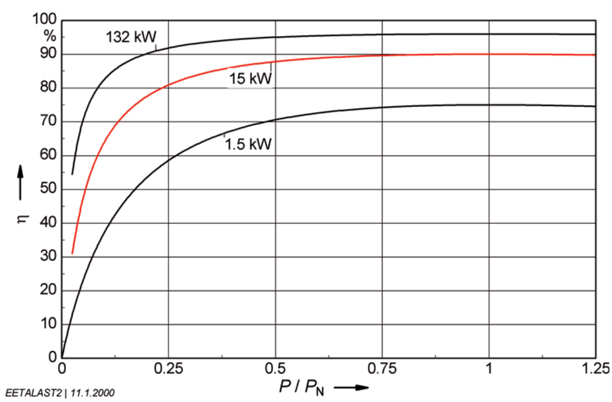


Figure 9.2
Typical pattern of the efficiency of 4pole cage induction motors as a function of the relative loading P/P_N

A detailed presentation of the subject of efficiency can be found in the Danfoss-Bauer publication SD 3401 “Saving energy with geared motors”.

III GEAR UNIT TYPES AND RATINGS

10 Helical gear unit with coaxial output

The creators of the first Bauer geared motors designed at the end of the 1920s had a slow running electric motor in mind as a model: Fitting at the base of the motor and a central output shaft (**Figure 10.1**). Admittedly nowadays the inevitably high reaction forces are fed directly via the gear unit enclosure to the base plate – yet the fundamental concept of a coaxial drive has been retained (**Figure 10.2**). Alongside many further developments this “classical” design dominates, and thanks to its being produced in large numbers (**Figure 10.3**) it can also be manufactured economically (Figure 14.2).

Figure 10.1
BAUER geared motor model 1938

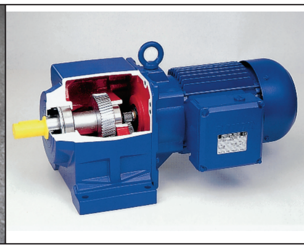


Figure 10.2
Danfoss-Bauer helical-geared motor of the generation 2000

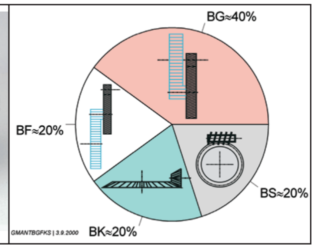


Figure 10.3
Types of geared motors: BG helical / BF flat / BK bevel / BS worm production value (1999)

Some of the design elements are also used within the modular system for the other types: BF shaft-mounted geared motor (Section 11), BK bevel-geared motor (Section 12) and BS worm-geared motor (Section 13); they are therefore described below.

10.1 Pinion fit on the rotor shaft

Figure 10.1.1 shows an example of the construction difficulties associated with the design and mounting of the input pinion:

- AR 1 is a slip-on pinion with a relatively strong hub on a correspondingly weak shaft journal.
- AR 2 shows a relatively thick shaft journal. The residual cross section between the pinion keyway and tooth space is inevitably weakened.
- AK shows a solution which aims to avoid the above disadvantages. If the fit is poor, however, the pinion is at risk when pushed on because of the explosive effect of the conical shaft.
- ER shows a slip-in pinion which avoids all the above weaknesses. The entire pinion (including the shank) consists of high-strength hardened steel; it is shrunk.

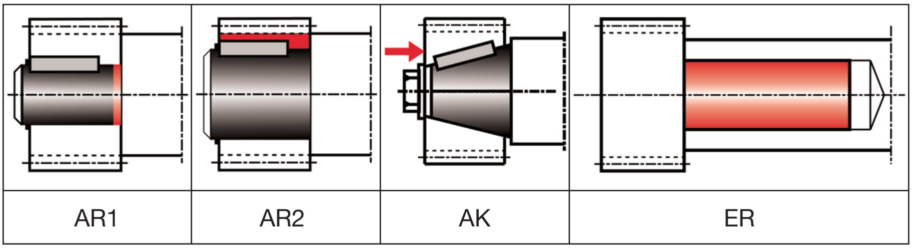


Figure 10.1.1
Examples for the constructive design of an input pinion
AR 1 – Slip-on pinion with a strong hub on a weak shaft journal
AR 2 – Slip-on pinion with a weak hub on a strong shaft journal
AK – Conical slip-on pinion at risk as a result of being pushed on wrongly
ER – Slip-in pinion, shank and gear made of high-strength hardened steel shrunk into the bore of the drive shaft

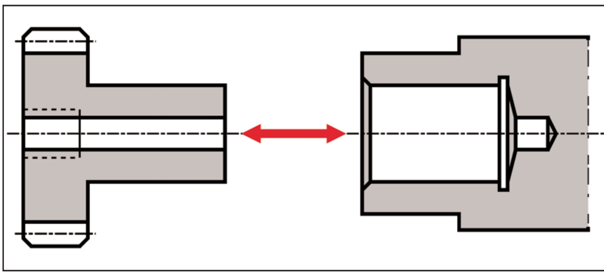


Figure 10.1.2
Slip-in pinion and rotor shaft with bore

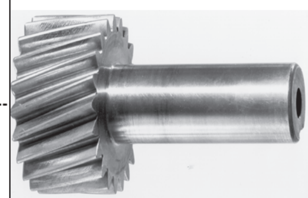
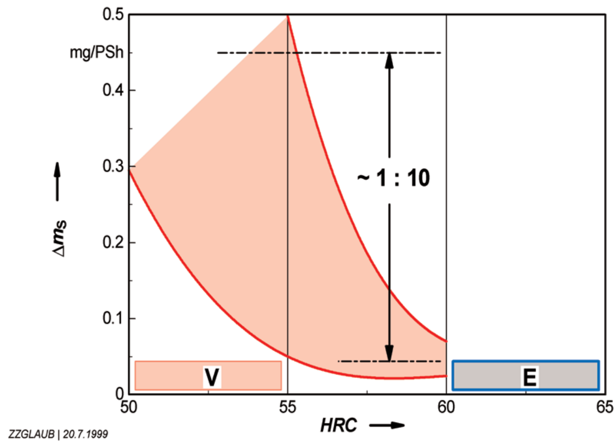


Figure 10.1.3
Slip-in pinion with smooth shank for shrunk-in fit

10.2 Gearwheel material and hardness

According to research carried out by Glaubitz following the FZG gear test in accordance with DIN 51354, **Figure 10.2** shows how strongly the specific wear Δm_s depends on the Rockwell surface hardness HRC of the teeth: With ***hardening and tempering*** (V) it is approximately 10 times higher than with ***case hardening*** (E).
All gearwheels in Danfoss-Bauer spur-gear units are manufactured using high quality manganese chrome steel and case hardened to 60 - 62 HRC. By comparison with through-hardened wheels, the relatively soft and tough core is stronger as regards impact stress and has better internal noise attenuation. Compared with wheels that are merely hardened and tempered or unhardened wheels, the load-carrying capacity and wear resistance are considerably better.

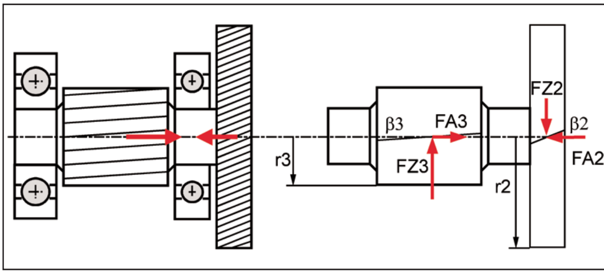
Figure 10.2
Specific wear
Δm_s in FZG gear rig test in accordance with DIN 51354 with varying Rockwell surface hardness HRC (according to *Glaubitz*)



V Range of hardened and tempered wheels
E Range of case-hardened wheels

10.3 Helix angle

Numerous experimental values and some known quantitative studies confirm the positive effects of the ***pitch of the helix*** on noise production. By contrast with the straight-toothed spur wheel, the line of contact for a helically toothed wheel does not run parallel to a tooth trace but at an angle across the tooth flank. For that reason when meshing begins there is no pulsed load thrust, but rather load bearing is even and constant. Together with the increased bite there is therefore ***less noise production***. The helical gearing, however, also results in an unwanted axial component from the radial force which has to be taken up by the rolling contact bearing. Above all, in the secondary gear reduction stages with relatively high torques and radial forces these axial forces can have a decisive impact on the dimensioning and service life of the bearing. In Danfoss-Bauer helical-gear units, therefore, only the first stages, which are primarily responsible for the overall noise levels, are halical to the extent required to reduce noise and permitted by the bearing service life. In the slow moving stages which produce less noise there is only a correspondingly small helix as shown in **Figure 10.3.1** which compensates to a large extent for the axial thrust from the first stage and relieves the rolling contact bearing. This pitch of the helix of just a few degrees therefore plays only a secondary part in reducing noise.



$$F_{A3} = F_{A2}$$

$$F_{Z3} = \tan\beta_3 = F_{Z2} \cdot \tan\beta_2$$

$$\frac{M}{r_3} \cdot \tan\beta_3 = \frac{M}{r_2} \cdot \tan\beta_2$$

$$\frac{\tan\beta_3}{r_3} = \frac{\tan\beta_2}{r_2}$$

Figure 10.3.1
Basic arrangement of the pitch of the helix in wheels R2 and R3 mounted on a “pinion shaft” to extensively compensate for the axial force F_{A2} from the fast moving and therefore potentially noisy first stage

If the rolling contact bearing is not relieved, the increased pitch of the helix β_0 in the first stage, required to reduce noise, inevitably leads to a severe reduction in the relative service life L_β/L_0 of the rolling contact bearing, as is clearly shown in **Figure 10.3.2**.

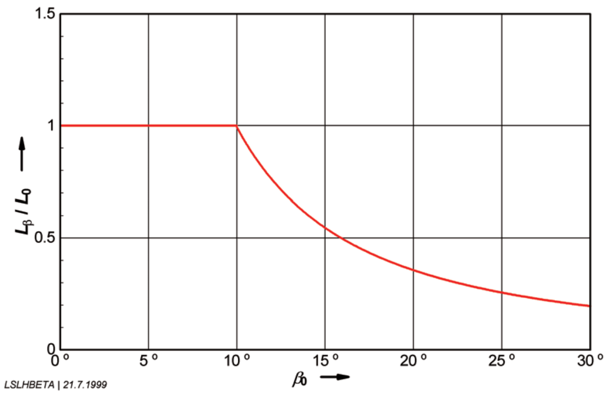


Figure 10.3.2
Relative theoretical service life L_β/L_0 of a ring-grooved bearing in relation to the helix angle β_0 of a helical-gear stage

The influence of the helix angle on noise production can only be represented quantitatively with a large spread. In this connection it is interesting to consider a series of tests conducted by *Hösel* (VDI [Association of German Engineers] conference “Gearwheels and Gear Trains”), according to which increasing the helix angle b0 from 0° to approximately 20° while retaining the machining quality achieved noise reduction of up to 10 dB; an increase from 20° to 30°, however, only achieved a noise reduction of about 1 – 2 dB.
An optimum gear unit design therefore aims at a sensible compromise between low noise levels and good service life

11 Shaft-mounted gear unit with parallel drive

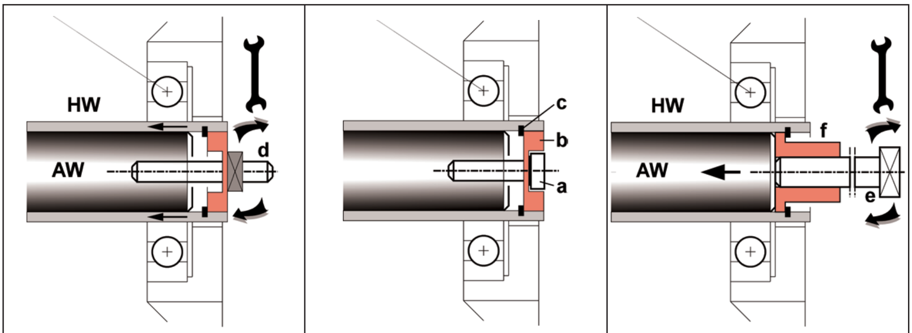
The design and benefits of the shaft-mounted gear unit have been discussed in detail in Section 1.7. Using the BF slip-on geared motor as an example some features of the ***flat gear*** are considered.

11.1 Hollow shaft design

Removing the shaft-mounted gear unit after it has been in operation for a long time can be made a great deal easier if appropriate measures have been taken at the project stage for the shaft being driven.

11.1.1 Hollow shaft with key

With this solution a large part of the torque is transmitted through friction in the seat of the key. For this reason appropriate precautions are necessary for removing and fitting the hollow shaft on the driven shaft.
Figure 11.1.1 shows the simple solution of a fitting aid where a normal hollow shaft is used. These additional parts should be taken into consideration, though, when dimensioning and designing the driven solid shaft.



① Pushing on	② Setting axially	③ Pulling off
A threaded bolt (d) is placed into the end thread of the shaft to be driven (AW). The hollow shaft (HW) of the slip-on gear unit is pressed onto the shaft over the pressure piece (b) and retaining ring (c) with the aid of the nut.	The pressure piece (b) is rotated and fitted against the retaining ring (c) using the Allen key bolt (a). The hollow shaft and shaft to be driven are set mutually.	An extractor (f) is fitted between the end face of the shaft and the ring (c). The jack screw (e) pushes against the shaft end face of the shaft to be driven (AW) and removes the slip-on gear unit‘s hollow shaft (HW).

Figure 11.1.1 Fitting aids for shaft-mounted gear units

11.1.2 Hollow shaft with shrink-disc connection (SSV)

This solution offers the following benefits:

- ☐ Hollow shaft / solid shaft sliding seat for mounting and dismantling
- ☐ Shaft not weakened by keyway
- ☐ Larger shaft dia with components that are otherwise the same – no keyway
- ☐ At extreme torque peaks the frictional connection works like a sliding clutch and so avoids major damage to the gear unit.

The mounting principle is shown in **Figure 11.1.2**.

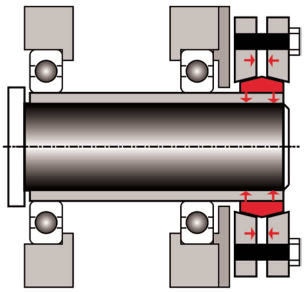


Figure 11.1.2
Principle of a hollow shaft with shrink-disc connection (SSV)
1 – Driven shaft
2 – Hollow shaft
3 – Inner ring
4 – Straining screws
5 – Outer rings

11.2 Torque arm

The ***reaction torque*** must be taken up by a suitable torque restraint. Care must be taken that this does not cause any unacceptably high constraining forces (e. g., when the driven shaft runs out of true). On the other hand, too much play on starting or reversing can result in dangerously high shock torques. Consequently, we recommend the use of pre-tensioned rubber damping elements.

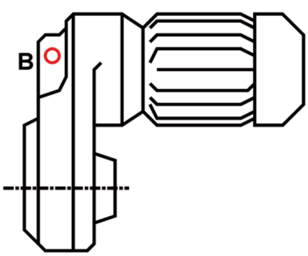
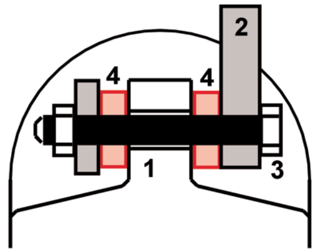


Figure 11.2.1
Structurally designed fixing point (B) for the torque arm on a shaft-mounted flat-geared motor

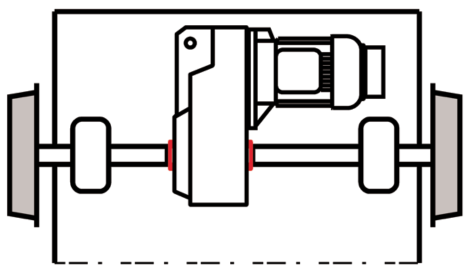
Figure 11.2.2
Pre-tensioned rubber buffers on torque restraint (B) to avoid constraining forces due to bad tolerances and shock load resulting from play
1 Torque arm on shaft-mounted gear unit
2 Fixing point on driven machinery
3 Bolt
4 Pre-tensioned rubber buffers



11.3 Example of application in vehicles

As an example of the space-saving mounting of a shaft-mounted flat-geared motor, **Figure 11.3** shows the drive of a vehicle where the drive motor does not restrict the "driving profile".

Figure 11.3
Space-saving mounting of a shaft-mounted flat-geared motor in a vehicle



11.4 Cost comparison

The cost comparison is indeed based on some assumptions, but nonetheless shows price is a significant benefit for the shaft-mounted version. The relation can vary depending on the type of coupling and cost of the ***console***. Whilst coupling costs stay within certain limits, the costs for foundation and console can vary considerably from one case to another. If, for example, the drive has been designed with coupling and console, it would definitely be more expensive than that assumed as the basis for the illustration in **Figure 11.4**.

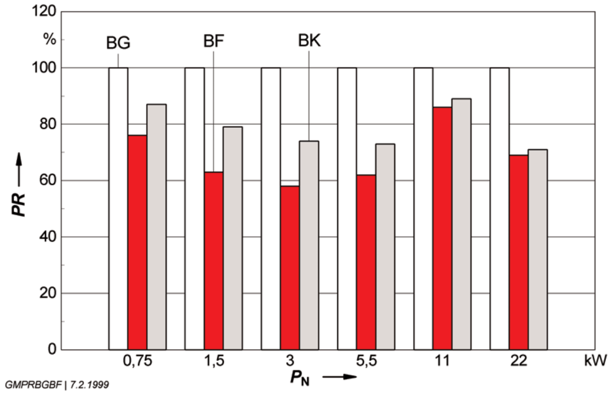


Figure 11.4
Cost comparison
BG-Helical-geared motor with coupling and console, foot-mounted
BF-Flat geared motor in the slip-on version with hollow shaft and key
BK-Bevel-geared motor in the slip-on version with hollow shaft and key

12 Bevel-gear units with right-angle drive

If the space at the place of installation is limited in an axial direction, it can be beneficial to mount the output shaft at right-angles (see Figure 1.7.4). The advantages and disadvantages of these solutions with bevel gear stage or
worm-gear stage can be assessed depending on the type of drive.

12.1 Bevel-gear stage mounting

In the search for a solution in terms of a module for series-produced products, structural principles have to be weighed against optimum multiple use of the components. **Figure 12.1.1** shows the structure and **Figure 12.1.2** shows a practical application of a BK bevel-gear unit from the bevel-geared motor range where a helically toothed gear stage is used as an input stage. Although this results in relatively large (expensive) stages on the intersecting shafts, this allows for multiple use of the motor and the helical-gear stage can be integrated into a ***modular system***.

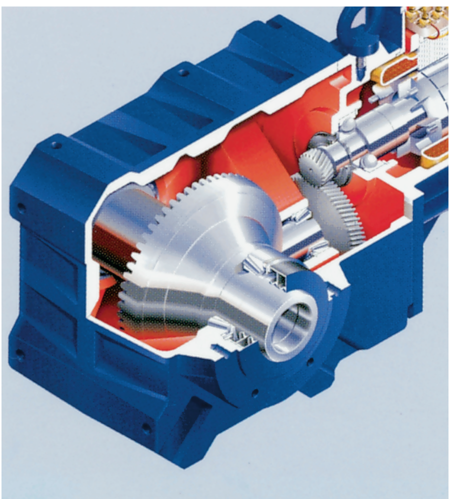


Figure 12.1.1
Sectional drawing of a bevel-gear unit with helically toothed gear stage at the input and spiral bevel gear end stage

Figure 12.1.2
Example of the use of a bevel-geared motor from the BK geared motor range on a hoist

12.2 Cost comparison bevel-gear unit – worm-gear unit

Compared with the worm-gear unit, the ***bevel-gear unit*** is more efficient and has less flank wear.
For this reason the bevel-gear unit is the better choice, particularly for drives in ***continuous operation***; any possible increase in investment costs are quickly compensated for by the lower energy consumption as the calculation in **Figure 12.2** shows:
The additional cost of the bevel-gear unit is therefore recouped after approximately 1.8 years or 22 months for single-shift operation ***by the savings on electricity costs alone*** – this would take only about 0.6 years or 7 months in the case of three-shift operation. The bevel-gear unit will be operating at greater cost-efficiency after this period.

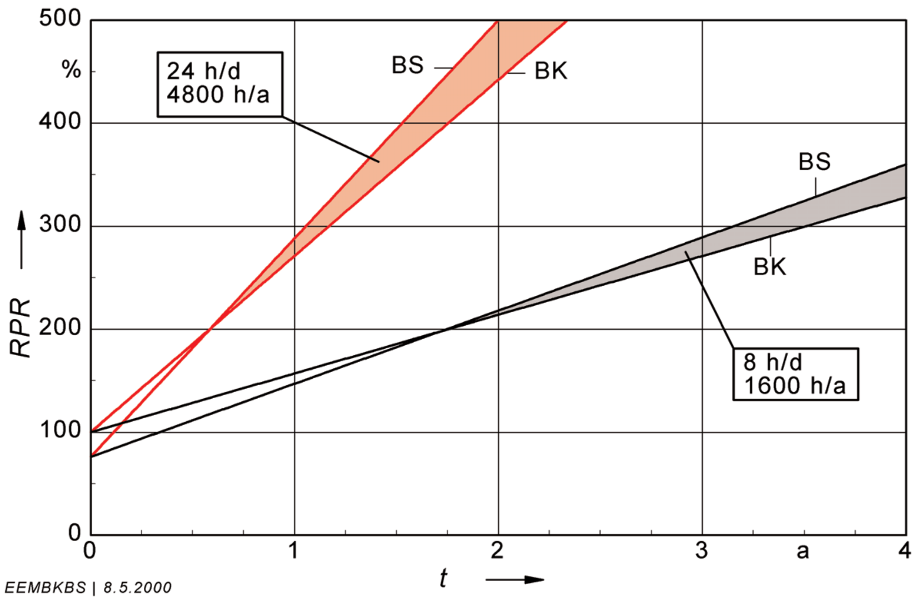


Figure 12.2
Relative operating costs *RPR* (excluding maintenance) at approximately 500 Nm, 27 r/min as a function of the operating time *t* (in years)

BK – Bevel-geared motor
BS – Worm-geared motor
The following two assumptions are made about the operating time:
Red: 24 hours per day (h/d), 200 days per year, 4800 hours per year (h/a)
Black: 8 hours per day (h/d), 200 days per year, 1600 hours per year (h/a)

13 Worm-gear units with right-angle drive

Worm-gear units allow very high reduction ratios in a stage (up to $i > 30$).
There is very little risk of tooth breakage and they produce very little noise. However, the sliding friction – unlike the largely rolling movement on an involute cylindrical gear – produces relatively high friction losses and temperatures; its level of efficiency decreases with increasing reduction ratio. At high reduction ratios (low levels of efficiency < 50 %) ***self-locking*** occurs – the gear unit helps to stop the downward movement of a load.

13.1 Example of the design of the BS worm-geared motor range

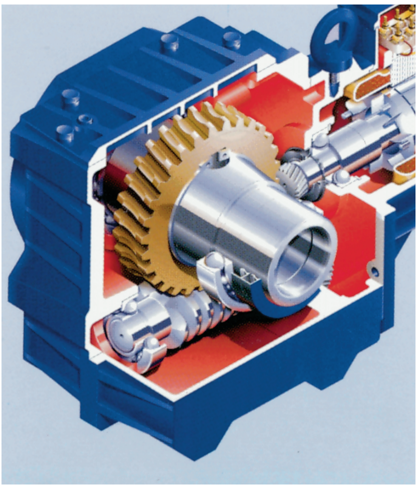


Figure 13.1.1
Sectional drawing of a worm-gear unit with helical-gear stage at the input and with hollow shaft

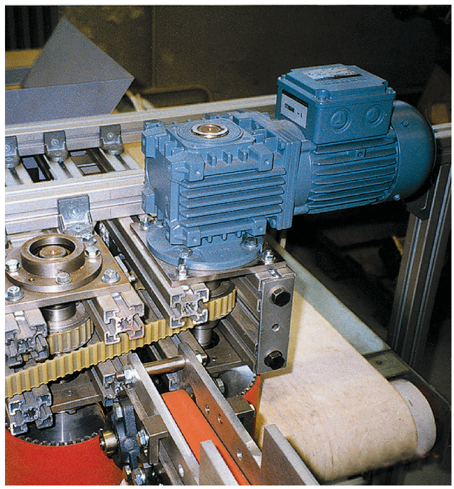


Figure 13.1.2
Example of the use of a worm-geared motor from the BS geared motor range

13.2 Price comparison worm-gear unit – helical-gear unit

Worm-gear units are often viewed as being cheaper than helical-gear units. This assumption may be justified in very high reduction ratio ranges (low speeds) and in countries where the proportion of worm-gear units manufactured is traditionally high – but not at standard speeds and in markets where a high proportion of helical-gear units are produced. **Figure 13.2.1** shows the proportions of helical-gear units (H) and worm-gear units (S) based on the number of units produced in 1998 by German manufacturers (according to VDMA data).

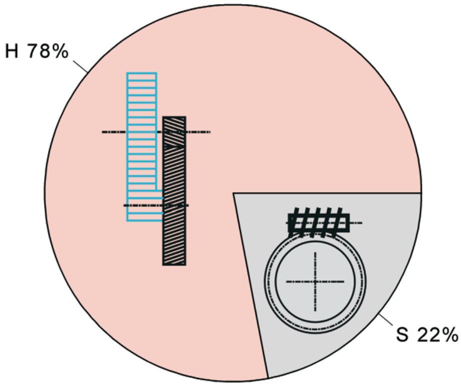


Figure 13.2.1
Proportions of helical-gear units (H) and worm-gear units (S) based on the number of units produced in 1998 in Germany (according to VDMA data)

Thanks to rational manufacturing, helical-gear units are generally cheaper than worm-gear units, as the comparison in **Figure 13.2.2** shows.
Price is therefore no reason for purchasing a worm-gear unit since it has a higher energy consumption.

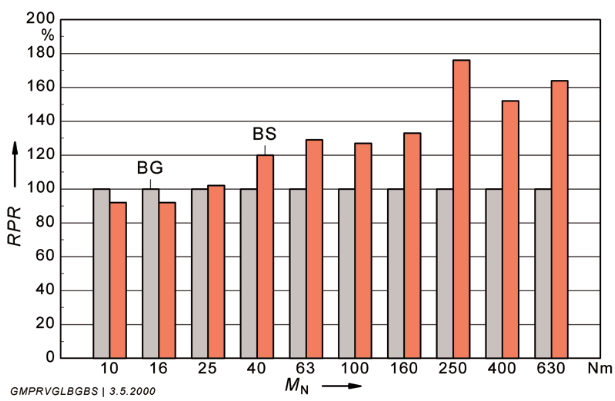


Figure 13.2.2
Price comparison

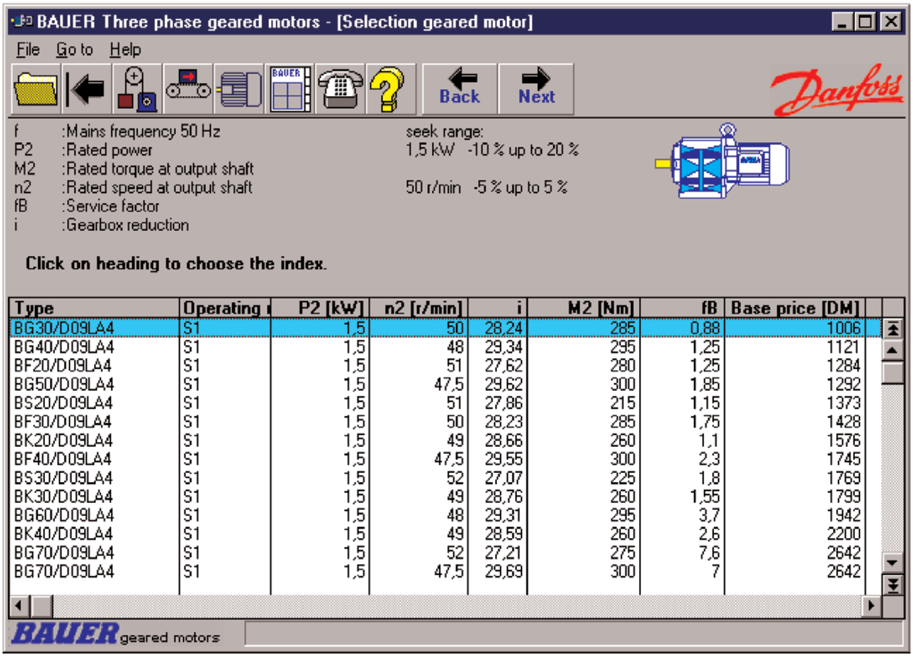
BG
Helical-geared motors

BS
Worm-geared motors

at rated torques M_N

14 Direct comparison BG – BF – BK – BS

Usually the first decision with regard to choosing the drive is whether a right-angle drive is required. The only alternatives to choose between, therefore, are concentric/parallel drive (BG/BF) or bevel-gear/worm-gear (BK/BS); detailed information about these has been offered in Sections 11.4 and 12.2.
Unlike the printed catalogue, the catalogue CD makes direct comparison between all four types of gear unit a very quick process, particularly if, for example, the decision is to be based entirely on price. **Figure 14.1** shows the result of a search for a drive for 1.5 kW, approx. 50 rpm at service factor fB ≈ 1.



Type	Operating	P2 [kW]	n2 [r/min]	i	M2 [Nm]	fB	Base price [DM]
BG30/D09LA4	S1	1,5	50	28,24	285	0,88	1006
BG40/D09LA4	S1	1,5	48	29,34	295	1,25	1121
BF20/D09LA4	S1	1,5	51	27,62	280	1,25	1284
BG50/D09LA4	S1	1,5	47,5	29,62	300	1,85	1292
BS20/D09LA4	S1	1,5	51	27,86	215	1,15	1373
BF30/D09LA4	S1	1,5	50	28,23	285	1,75	1428
BK20/D09LA4	S1	1,5	49	28,66	260	1,1	1576
BF40/D09LA4	S1	1,5	47,5	29,55	300	2,3	1745
BS30/D09LA4	S1	1,5	52	27,07	225	1,8	1769
BK30/D09LA4	S1	1,5	49	28,76	260	1,55	1799
BG60/D09LA4	S1	1,5	48	29,31	295	3,7	1942
BK40/D09LA4	S1	1,5	49	28,59	260	2,6	2200
BG70/D09LA4	S1	1,5	52	27,21	275	7,6	2642
BG70/D09LA4	S1	1,5	47,5	29,69	300	7	2642

Figure 14.1 Search result from the catalogue CD for the alternatives for 1.5 kW, 50 r/min, service factor $f_B \approx 1$; ordered according to price (current in 2000)

Figure 14.2 shows a trend for six power stages in the range 0.75 to 22 kW, in each case for some 50 r/min; however, this need not apply to each specific individual case. The cheapest is the BG helical-gear unit – the dearest is the BK bevel-gear unit. However, this “direct comparison” does not take into account the considerable advantages of the “shaft-mounted gear unit” solution (see Section 11.4).

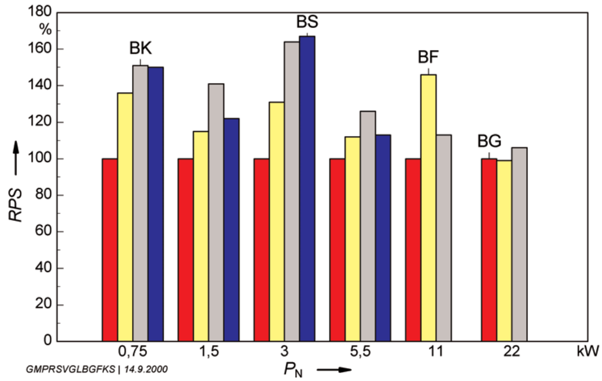


Figure 14.2
Direct comparison of the relative gross prices of geared motors of types
BG
Helical gear (concentric)
BF
Slip-on flat-gear
BK
Bevel-gear unit
BS
Worm-gear unit

BG Helical-gear unit	**BF** Flat-gear unit	**BK** Bevel-gear unit	**BS** Worm-gear unit

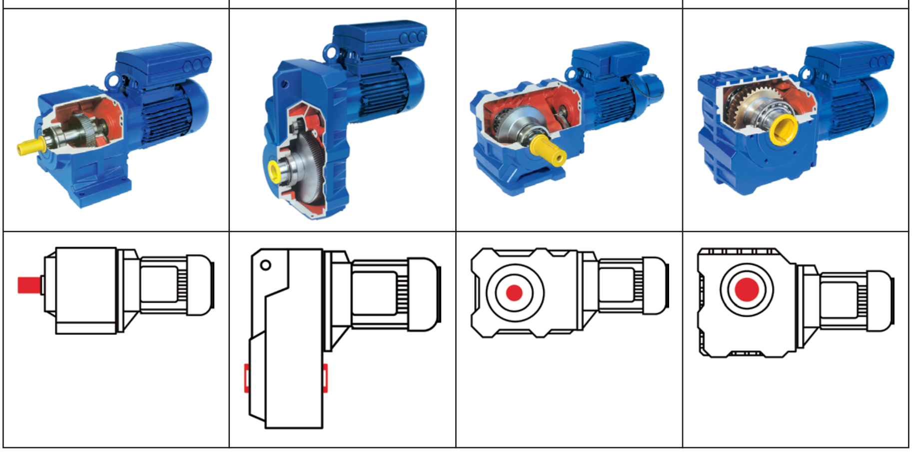


Figure 14.3 Illustration of the principle of the four types of Danfoss Bauer GmbH gear unit

15 Gear unit efficiency

In the 1972 edition of DIN VDE 0530, clause 27 states that the specified output for geared motors must be based on the final speed of the slow-running shaft. This clarity was sacrificed in favour of international harmonisation; an equivalent instruction can now only be found in clause 9 of DIN 42961 “Rating plates for electrical machines”. Often standard motors with their own rating plate are mounted on a speed-transforming gear with a separate rating plate, and its efficiency must then be assessed by the user.

15.1 Helical-gear units and bevel-gear units

Losses in the region of 2 % per stage are to be expected for these types of gear unit, related to the rated utilisation of the gear unit. Nearly half of these losses occur under no-load – mainly in the form of ***churning work*** in the lubricant (**Figure 15.1**); these losses increase slightly with the speed.

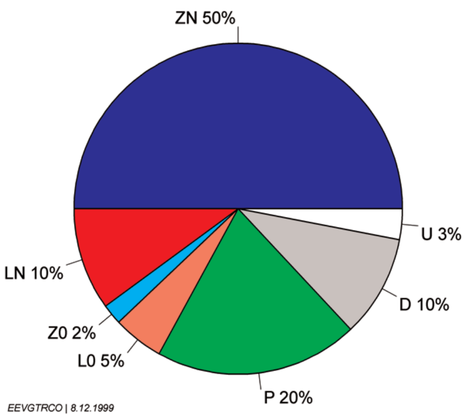


Figure 15.1
Gear loss components on oil-lubricated helical-gear units

No-load:
Z0 – Gear teeth
L0 – Bearings
P – Churning
D – Seals
U – Additional

Nominal load:
ZN – Gear teeth
LN – Bearings

The reduction ratio per stage has ***no*** practically ***measurable effect*** on the level of efficiency (**Figure 15.2**).

Detailed information on the efficiency of geared units is available in the special publication SD 34. “Saving energy with geared motors” published by Danfoss Bauer GmbH.

15.2 Worm-gear units

Unlike helical-gear units, the losses on worm-gear units are directly dependent on the reduction ratio. Worm-gear units have a considerable price advantage over helical gears at very high reduction ratios - although this advantage is tempered by a considerably poorer level of efficiency (**Figure 15.2**).

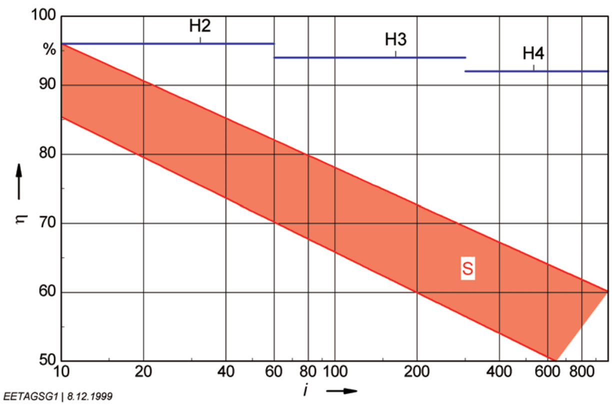


Figure 15.2 Guide values for efficiency η of helical-gear units (H) with 2, 3 or 4 stages compared to worm-gear units (S) depending on the reduction ratio *i*, in relation to the rated output of the gear unit

The total losses on worm-gear units may be broken down as follows:
- ☐ Screw rolling friction (sliding friction)
- ☐ Churning work
- ☐ Bearing friction
- ☐ Seal friction.

Even at small reduction ratios ***sliding friction*** prevails; it becomes a crucial component at medium and high reduction ratios. Improved lubricants (e. g., synthetic oils in place of mineral oils) may reduce the sliding friction considerably and thus cause a marked improvement in the level of gear unit efficiency (e. g. of up to 10 to 15 percent according to recent literature and measurements). Changes in these values can be quantified using measuring technology – they also cause a reduction in the operating temperature and an increase in the service life.
The figures quoted correspond to the current state of the art in lubrication technology and manufacturers‘ specifications. Further improvements are not expected in the near future due to the relatively high gearing losses on worm-gear units as a result of their operating principle.

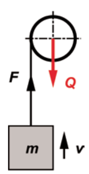
16 Output shaft radial force

Where slow running drives – i.e. geared motors – are used, ***large driving forces*** are generally necessary. Using a direct coupling, these external forces usually emerge as a pair and do not represent an additional load on the shaft end and the output shaft bearings. The driving forces are usually transferred by means of positive engagement or force-closed traction elements (e. g. chains or belts) and their reactions thus work as transverse forces on the output shaft.
The following sections detail how, if the wrong power transmission component is selected, these transverse forces can reach impermissible levels without exceeding the rated power, torque, current or temperature tolerances. This means that overhung force overload protection cannot be carried out secondarily using any monitoring device, but only primarily using the ***correct design*** (see section 39).

16.1 Height and direction of the radial force

The drive unit geared motor is rated thermally and mechanically during continuous running duty to transfer a specific basic torque M_N. On the external power transmission components – e. g. chain wheel, gearwheel, V-belt pulley, crank – this basic torque is converted into effective driving force F which can be calculated using the following relations:

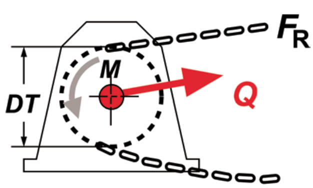
16.1.1 Translation



$$F = \frac{1000 \cdot P}{v}$$

Figure 16.1.1
F – Driving force in N
P – Driving power in kW
v – Velocity in m/s
Q – Radial force on the output shaft

16.1.2 Rotation



$$M = \frac{9550 \cdot P}{n}$$

$$F = \frac{M}{D_T/2} = \frac{19100 \cdot P}{n \cdot D_T}$$

Figure 16.1.2
M – Driving torque in Nm
P – Driving power in kW
n – Rot. speed in r/min
F – Driving force in N
D_T – Pitch circle diameter of driving element (e. g. gearwheel, sprocket) in m

16.2 Driving elements with positive engagement power transmission

When using transmission elements with ***positive engagement***, such as chains, gearwheels, toothed belts, push rods and eccentrics, resistance works against the effective driving force *F* acting on the geared motor output shaft as an overhung load *Q* (see **Figure 16.3.1**).

16.3 Chain drive

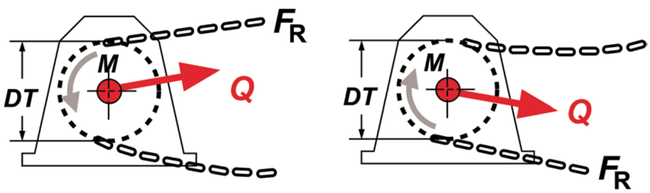


Figure 16.3.1
Loading on the output shaft with a chain drive

The chain pull *F* acts as a radial force *Q* on the output shaft in the direction of the taut side of the chain. The chain lies on the chainwheel in the form of a polygon; hence, the effective pitch circle diameter and the chain speed will vary in the ratio of 1 : cos α, where α is half the angle between adjacent teeth on the chainwheel (α = 180/Z). This ***polygon effect*** becomes more pronounced as the number of sprocket teeth *Z* is reduced. Among other reasons, this is why DIN 8195, “Selection of chain drives” recommends that chainwheels with at least 17 teeth be chosen. The chainwheel manufacturer will certainly normally support this recommendation, but may also offer drives with as few as 10 or 11 teeth on the chainwheel.

16.4 Toothed gearwheel drive

The force on the teeth *F* in toothed gear wheels is at a ***meshing angle*** of 20° to the common tangent to the pitch circles of the driving and driven wheels (**Figure 16.4.1**). The driving tooth force *F* (grey arrows) acts on the driven wheel. On the driving wheel, it acts as reaction force (black arrows). The effect of this reaction on the output shaft can be considered as a radial force Q acting on it (red arrows).

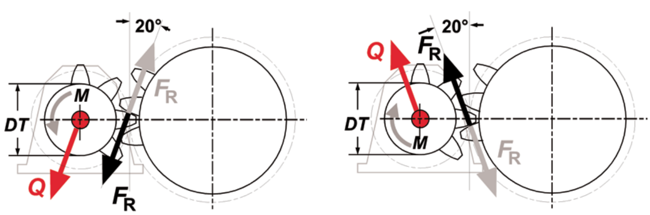


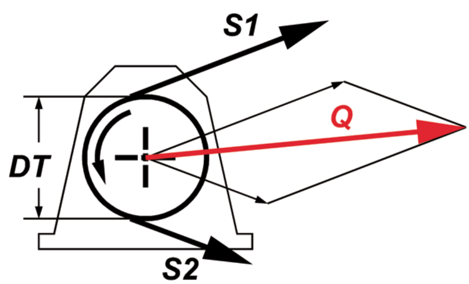
Figure 16.4.1
Loading the output shaft with a toothed gearwheel drive

16.5 Driving elements transmitting forces by friction

When using transmission elements ***relying on friction***, such as flat belts or V-belts, it is necessary to ***pretension*** them before they can transmit power. In such cases, the overhung load on the output shaft consists not only of the usable belt pull but also the initial tension.
The initial tension on the belt should be set just high enough to ensure reliable, slip-free power transmission out of consideration for the belt and bearings. Since belt-tensioning devices often permit easy, but uncontrolled tensioning of belts, it is not uncommon to find belt drives with excessive pretensioning in everyday practice. It is recommended that appropriately large safety factors be used and generously dimensioned output shaft bearings be chosen when calculating the resulting transverse forces.

16.6 Belt drive

Figure 16.6
Radial force *Q* on the output shaft resulting from the belt forces *S1* and *S2* on a belt drive



S1 and *S2* are operational belt forces due to pretension and belt pull *F*.
Q is the radial force acting on the output shaft, between the taut and the slack side of the belt, but tending towards the direction of the former. The following apply, according to the pretension

- ☐ for V-belts: $Q = (2 \text{ to } 2.5) \cdot F$
- ☐ for flat belts: $Q = (2 \text{ to } 3) \cdot F$.

The output shaft bearings must be dimensioned to take the total overhung load *Q*.

16.7 Friction wheel drive

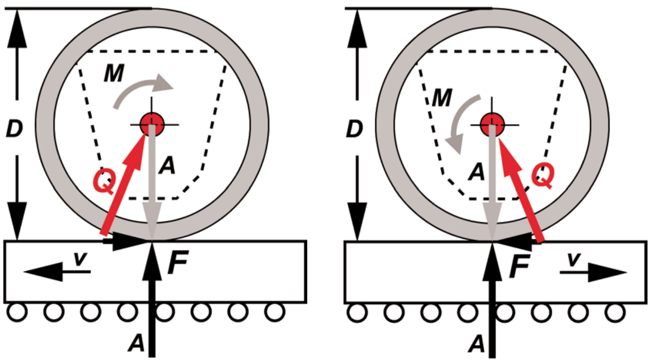


Figure 16.7
Loading on the output shaft with a friction drive

In order to transmit the available tangential force *F* to the load, the friction wheel must be pressed against that load with a ***force A*** (see **Figure 16.7**). The contact pressure must be at least

$$A = \frac{F}{\mu}$$

where μ is the coefficient of friction between the friction wheel and the load.

The resultant force acts as a transverse force on the output shaft

$$Q = \sqrt{A^2 + F^2}$$

Under normal conditions encountered in practice $Q = (3 \text{ to } 4) \cdot F$.

16.8 Load capacity of the output shaft bearings

The total load on the output shaft bearings of a geared motor is composed of the tooth force generated within the gear unit and the external radial force.
Details of the permissible radial loading can be obtained from the catalogue data. Choosing an inappropriate diameter or fitting a power transmission component can result in the transverse force reaching impermissibly high levels without exceeding the rated output. This type of overload is expressed ***neither through excessive power consumption nor through heat build-up from exceeding the rated torque, and can therefore not be recorded using thermal methods***. The permissible overhung force also depends on a number of other factors: Gear unit size and bearing mounting on the output shaft, direction of force and direction of rotation as well as torque and output shaft speed.
Overload protection features to protect from overload due to excessive radial forces must therefore be introduced at the power transmission component ***design stage***. The maximum permissible transverse forces for all criteria should be obtained from the manufacturer of the geared motor. The size and arrangement of the power transmission component (e. g. a chainwheel) may have a decisive effect on the service life.

You will find further information on this topic in the Danfoss-Bauer book “Protective measures for three-phase geared motors”.

16.9 Optimising the gear box using finite element analysis (FEA)

When calculating the permissible radial force on the output shaft of a geared motor, the following things, among others, should be noted:
- ☐ The degree of radial force
- ☐ The distance of the point of application from the bearing and the shaft collar
- ☐ The direction of force
- ☐ The direction of rotation
- ☐ The internal radial and axial forces (from tooth helix) on the end wheel
- ☐ The output shaft bearing spacing
- ☐ The roller bearing load rating
- ☐ The output shaft speed.

Despite these many parameters, the shaft and bearing load can be easily determined in the same way using conventional calculation methods.
The space requirements and the weight of the gear unit are largely determined by the housing. ***Finite element analysis (FEA)*** can be used in complex calculation programmes to optimise the complicated geometric form of the gear box. **Figure 16.9** shows three individual illustrations combined: On the right is the standard housing view; in the centre is the model‘s mesh with manual matching in the important areas for strength; the shading on the left shows the enclosure load. The gesr box load calculated from the maximum permissible radial force of 20,000 N is within the permissible range. Even in a worst-case-scenario, the housing would be sufficiently protected against breakage.

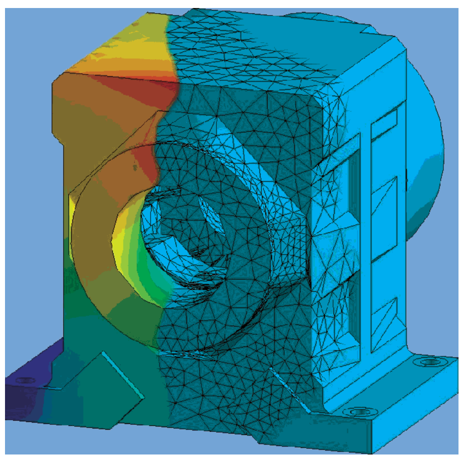


Figure 16.9
Simulation of a radial force of 20,000 N acting from below on the output shaft of the Danfoss-Bauer 2000 series BG70 gear box

Key to the colour code for loads:

Dark blue	no load
Light blue	light load
Green	medium load
Yellow	heavy load
Red	maximum load

17 Lubrication

Unlike electric motors, which have been standardised to some extent, there are wide variations in the design, utilization and construction of reduction gearing. The following general instructions refer to lubrication using a high-grade mineral oil and should be supplemented by the specific service regulations for the particular model.

17.1 Viscosity

The viscosity of an oil, together with its viscosity/temperature characteristic (represented by a VT graph), is decisive above all in start-ups at low ambient temperatures, and in sealing at high operating temperatures. It is of secondary importance for the ***pressure absorbing capacity*** on low-speed, highly-loaded gear units. **Figure 17.1** compares a few viscosity grades commonly used in practice. Classification into ISO ***viscosity grades*** (ISO VG) has been implemented internationally and is used by mineral oil suppliers. The ***Engler grades*** common in the past have been included in the comparison as these indicate how many times longer than water (1 °E) the oil will take to flow out of a test container and so provide a very clear overview.

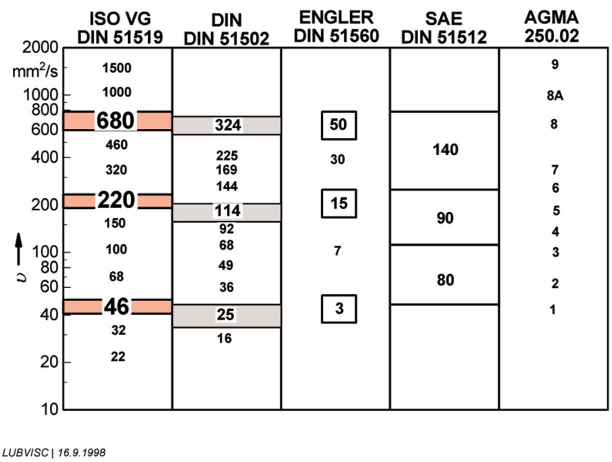


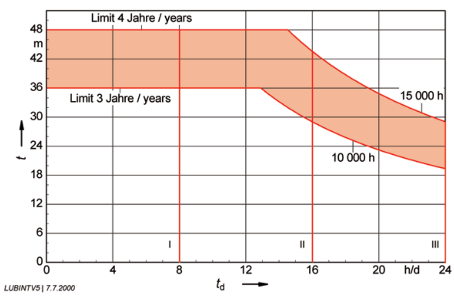
Figure 17.1 Comparison of common international viscosity grades (kinematic viscosity ν at a reference temperature of 40 °C)

17.2 High-pressure properties

Because no ***hydrodynamic lubricant wedge*** is formed between the tooth flanks in the low-speed stages of reduction gearing, chemical additives are used in modern high-performance lubricants to build up a boundary layer on the gear tooth surfaces and thus prevent metal-to-metal contact under high tooth loads. The oil is “doped” or “inhibited”. The minimum requirements on the properties of lubricants for the second filling are described in DIN 51517-3 for CLP lubricating oils, or may be found in the gear unit manufacturer‘s operating instructions.

17.3 Relubrication interval

The operating temperature has a strong influence on the service life of a mineral oil. Global specification of the correct relubrication intervals is therefore highly problematic. As a practical rule of thumb, a relubrication interval of about 10,000 ... 15,000 operating hours or a maximum time of about 3 ... 4 years has been found satisfactory. To the user, this relatively long interval seems reasonable, particularly if one compares it with the normal frequency of oil changes for a motor vehicle gearbox. At an average speed of 50 km/h, the normal service interval of 50,000 km would correspond to an operating time of only 1,000 hours! It would seem appropriate at this point to compare the relubrication interval of 10,000 hours or 3 years to actual running times found in practice (**Figs. 17.3.1** and **17.3.2**):
For a standard 5-day week (5 d/w), a daily running time of up to roughly 13 hours (13 h/d) is permissible without causing a reduction in the limit value of 3 years = 36 months (36 m). It is only when the average daily utilisation exceeds 13 h/d that the 10,000 hour limit would come into play and cause the interval between oil changes to be reduced.
The limit values are reduced for a 7-day week (**Figure 17.3.2**).



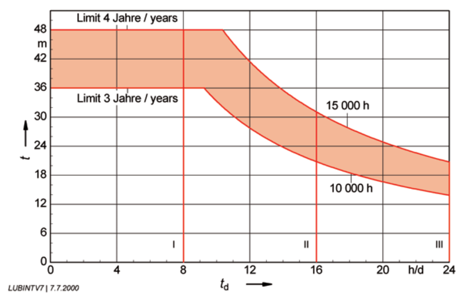


Figure 17.3.1
5-day week

Figure 17.3.2
7-day week

Time *t* (in months m) for the expiry of a relubrication interval of 10,000 ... 15,000 hours or 3 ... 4 years plotted against various operating periods t_d in hours per day

5-day week

Example	Shifts per day	Hours per day	Relubrication interval in months
I	1	8	36 ... 48
II	2	16	29 ... 43
III	3	24	19 ... 29

7-day-week

Example	Shifts per day	Hours per day	Relubrication interval in months
I	1	8	36 ... 48
II	2	16	21 ... 31
III	3	24	14 ... 21

The diagrams show that the relubrication interval of 3 ... 4 years can be adopted for the majority of running times encountered in practice. This statement applies for normal ambient temperatures (up to about 30 °C) and for high-quality mineral oils.
A ***running-in relubrication interval*** (e.g. 200 or 300 hours) is only necessary if either the inclusion of foreign objects in the gear unit enclosure or tooth flank wear is expected.
Provided the enclosure is thoroughly cleaned, the inside is coated with a fully adhesive paint and amply-sized, case-hardened and precision-machined gear wheels are used, this additional lubricant change can be omitted without detriment.

17.4 Synthetic lubricants

Apart from mineral oils, the properties of which are adequate for the majority of applications, synthetic lubricants (e. g. PGLP (polyglycols and synthetic hydrocarbons) lubricating oils) are also available. These have the following main advantages:

- ☐ high viscosity index (VI), thus suitable for extremely high temperature ranges
- ☐ good oxidation and ageing stability, and hence longer service life
- ☐ lower coefficient of friction, which can contribute to reduced losses and a longer service life, above all on gear units which experience a high degree of friction (worm gears).

Disadvantages:

- ☐ they attack certain materials in the gear unit (such as the inner coating, sealing materials, plastic bearing cages at temperatures above approximately 120 to 130 °C)
- ☐ reduced availability
- ☐ higher price
- ☐ polyglycols are not miscible or compatible with mineral oils
- ☐ special disposal requirements.

Any terms such as ***"lifetime lubrication"*** or ***"sealed for life"*** sometimes used in relation to synthetic lubricants should be viewed critically since the service intervals and service life of a gear unit do not depend merely on the lubricant.

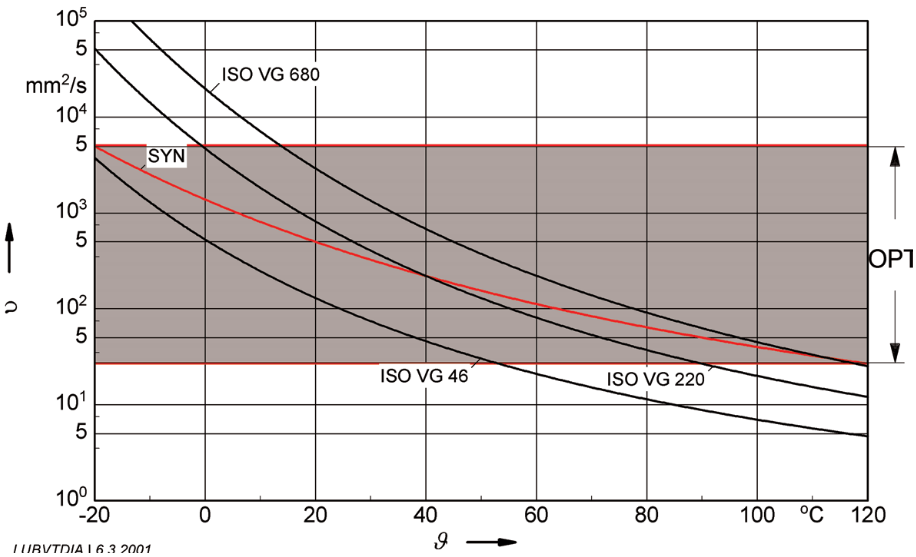


Figure 17.4
Kinematic viscosity ν as a function of temperature ϑ (VT characteristic) of ISO VG 46, 220 and 680 mineral oils compared to a synthetic oil (SYN)

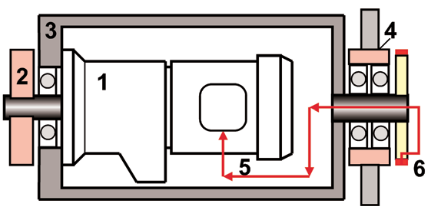
The same grade of synthetic oil can be used at temperatures from –20 °C to +120 °C in the viscosity range marked OPT. Two viscosity grades of mineral oil would be required given the same requirements on "optimum viscosity".

You will find full information about lubrication in the Danfoss-Bauer book "Protective measures for three-phase geared motors".

18 Drum motors

For many decades Danfoss-Bauer drum motors for driving ***conveying belts*** have held a firm position in conveying technology. The numerous advantages of this drive are valued by manufacturers and users of conveyors alike:

- ☐ Motor, speed-transforming gear and drive drum make up a single unit
- ☐ Minimum space requirement
- ☐ Favourable weight
- ☐ Completely enclosed design (IP65 protection in accordance with EN 50029); it is therefore dust and proof against water jets
- ☐ No external reduction ratio parts, therefore no awkward adjustment when mounting and no expensive safety apparatus
- ☐ Low-noise running due to high-grade gear units, precise manufacture, and sound absorbing grease lubrication
- ☐ Simple, clean installation
- ☐ Minimum maintenance costs, relubrication only after about 10 ... 15,000 operating hours. Thanks to its generous dimensioning, robust structure and enclosed design the service life of a Danfoss-Bauer drum motor is very long, especially if the information regarding selection and fitting of the drive is observed.



1 Flange geared motor
2 Output shaft fixing
3 Drum (belt conveyor)
4 Torque-free support
5 Current supply
6 Slip rings with drum speed

Figure 18.1
Structural relationship between the drum motor and geared motor

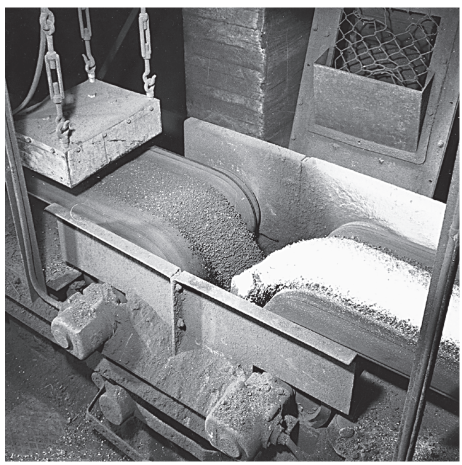


Figure 18.2
Drum motors in a foundry under conditions that would not be permissible for an open chain drive

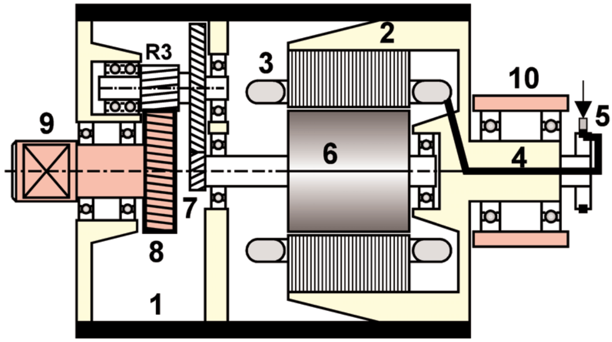


Figure 18.3
Schematic sectional drawing of a drum motor
1 Drum
2 Reduction casing for motor lamination stack
3 Winding
4 Hollow shaft
5 Slip rings for winding
6 Cage rotor
7 Gear unit stage I
8 Gear unit stage II (end gear stationary)
9 Output shaft (stationary)
10 Bushes

The functioning and structural relationship between the drum motor and geared motor are apparent in **Figure 18.1**:
If we imagine a geared motor (1) secured to its output shaft (2), then the whole outside cover would revolve around this shaft at a slow speed corresponding to the reduction ratio. A tube (3), supported on both sides, in which the geared motor is secured, forms the drum jacket. The current supply to the winding (5), itself rotating slowly with the drum, can be fed via slip rings and the hollow shaft (6).
In the actual design shown in **Figure 18.3** the drive drum also bears all the mounting parts, but here they are completely adjusted to the round shape of the tube. The reduction case for the motor unit is pressed in on one side; on the other side the gear casing is pressed in. If the drum diameters are the same but the drum lengths are different, only the lengths of the drum and rotor shaft will change; all other components remain the same. With this design, the unavoidable heat loss from the winding can run off on a direct conductive route to the drum surface, where it is taken off by the conveyor belt as if by a constantly renewed cooling compress.
In other types where a heat insulating air gap between the stationary winding and the rotating drum makes cooling more difficult, the fact that only a small amount of heat is carried off must be taken into consideration in the winding design. The drum jacket is turned by means of pronounced but not sharply edged ridges and its diameter is largest in the middle of the drum length so that the belt is driven centrally and as effectively as possible.

IV DUTY TYPES

19 Classification of duty types

With the exception of drives for special applications (e. g. hoists), standard motors are always designed for continuous running duty. Where drives are subject to frequent switching, it may be necessary to choose a special design in a larger frame size. Conversely, it may be possible to select a much smaller model for truly short-time duty. ***It is therefore necessary to advise the manufacturer of any duty type which differs from continuous running duty***. Doing so may also result in cost savings. The increasing automation of manufacturing processes has brought about a situation where electric drives are subjected to cyclical operation or used for positioning, that is to say in switched and braking duty. It has therefore become necessary to expand on the long-established terms such as “continuous running duty”, “intermittent periodic duty” or “short-time duty” to define the thermal rating of a drive. It takes 13 pages of size A4 to define “duty type” in the internationally harmonised edition of IEC 60034-1 and EN 60034-1. Unfortunately, the text is not always clear, despite its length. Extracts from it have been reproduced below as necessary to provide a general overview. The schematic diagrams and abbreviations for variables have been changed from those used in the standard to improve intelligibility.

19.1 Definitions

- ***Duty***
  The statement of the load(s) to which the machine is subjected, including, if applicable, starting, electric braking, no-load and rest and de-energized periods, and including their durations and sequence in time.
- ***Duty type***
  A continuous, short time or periodic duty, comprising one or more loads remaining constant for the duration specified, or a non-periodic duty in which generally load and speed vary within the permissible operating range.
- ***Break (Rest and de-energized)***
  Machine at rest whereby neither electrical power nor mechanical drive are supplied.
- ***Cyclic duration factor***
  The ratio between the period of loading, including starting and electric braking, and the duration of the duty cycle, expressed as a percentage.

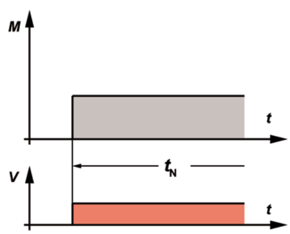
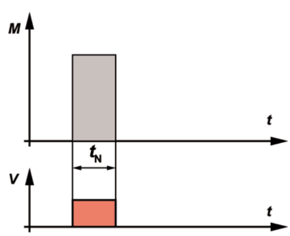
19.2 Declaration of duty

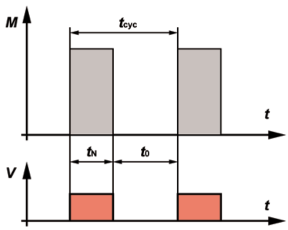
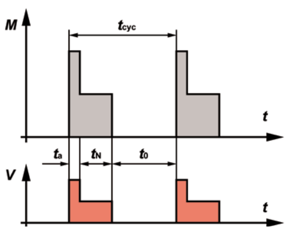
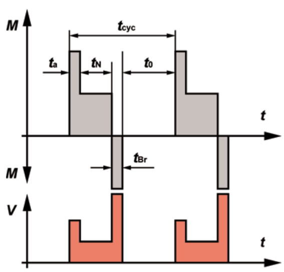
It is the buyer's responsibility to indicate a duty. The duty type may be indicated by an abbreviation. The designations must be written behind the load value. If the buyer has not indicated a duty, the manufacturer must assume that duty type S1 (continuous running duty) is sufficient.

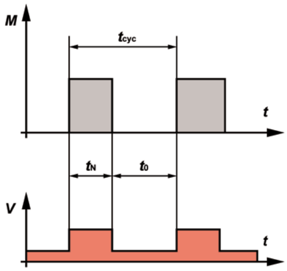
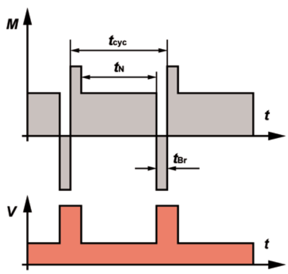
19.3 Duty types in accordance with the standard

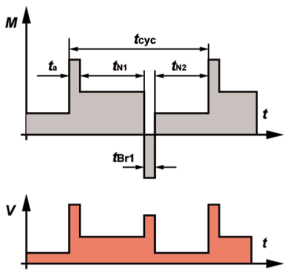
Explanation of the abbreviations used in the following table:

M	Load	t_N	Operating period at constant load
V	Electrical losses (P_V)	t_{Br}	Time with electrical braking
t	Time	t_0	Time at rest with de-energised windings
t_{cyc}	Period of one cycle		Cyclic duration factor = $(t_a + t_N + t_{Br})/t_{cyc}$
t_a	Run-up time		

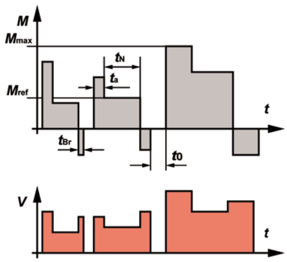
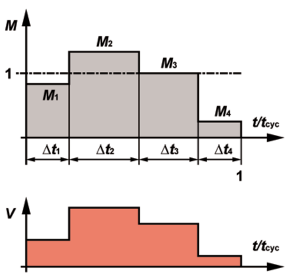
Previous designation Simplified diagram	**Abbreviations and definitions in accordance with the standard**
DB – Continuous running duty	**S1**
	**Continuous running duty** Operation at constant load of sufficient duration for the machine to reach thermal equilibrium. The corresponding designation is S1 or DB.
KB — Short-time duty	**S2**
	**Short-time duty** Operation at constant load during a given time less than that required to reach thermal equilibrium, followed by a rest and de-energised period of sufficient duration to re-establish machine temperatures within 2 K of the coolant. For example: S2 – 10 mins

<table>
<tr><td>AB — Intermittent
periodic duty</td><td>S3</td></tr>
<tr><td>
</td><td>Intermittent periodic duty
A sequence of identical duty cycles, each including a period of operation at constant load and a rest and de-energised period. In this duty, the cycle is such that the starting current does not significantly affect the temperature rise.
The designation is S3, supplemented by the cyclic duration factor.
For example: S3 – 25 %</td></tr>
<tr><td>ASB – Intermittent
switched periodic duty</td><td>S4</td></tr>
<tr><td>
</td><td>Intermittent periodic duty with starting
A sequence of identical duty cycles, each cycle including a significant period of starting, a period of operation at constant load and a rest and de-energised period.
The corresponding designation is S4, supplemented by the cyclic duration factor, the mass moment of inertia of the motor (JM) and the mass moment of inertia of the loading machine, (Jext), both in relation to the motor shaft.
For example: S4 – 25 % J_M = 0.15 kgm²</td></tr>
<tr><td></td><td>S5</td></tr>
<tr><td>
</td><td>Intermittent period duty with electric braking
A sequence of identical duty cycles, each cycle consisting of a period of starting, a period of operation at constant load, a period of rapid electric braking and a rest and de-energised period.
The corresponding designation is S5, supplemented by the cyclic duration factor, the mass moment of inertia of the motor (JM) and the mass moment of inertia of the loading machine, (Jext), both in relation to the motor shaft.
For example: S5 – 25 % J_M = 0.15 kgm²
J_{ext} = 0.7 kgm²</td></tr>
</table>

	S6
	**Continuous-operation periodic duty** A sequence of identical duty cycles, each cycle consisting of a period of operation at constant load and a period of operation at no-load. There is no rest and de-energised period. The corresponding designation is S6, supplemented by the cyclic duration factor. For example: S6 – 40 % (compare also duty type S3 with de-energised breaks)
DSB — Continuous running switched operation	**S7**
	**Continuous-operation periodic duty with electric braking** A sequence of identical duty cycles, each cycle consisting of a period of starting, a period of operation at constant load and a period of electric braking. There is no rest and de-energised period. The corresponding designation is S7, supplemented by the mass moment of inertia of the motor (J_M) and the mass moment of inertia of the loading machine, (J_{ext}), both in relation to the motor shaft. For example: S7 – J_M = 0.4 kgm² J_{ext} = 7.5 kgm² Cyclic duration factor = 1

	S8
	**Continuous-operation periodic duty with related load/speed variations** A sequence of identical duty cycles, each cycle consisting of a period of operation at constant load corresponding to a predetermined speed of rotation, followed by one or more periods of operation at other constant loads corresponding to different speeds of rotation (carried out, for example, by means of a change of the number of poles in the case of induction motors). There is no rest and de-energised period. The corresponding designation is S8, supplemented by the mass moment of inertia of the motor (J_M) and the mass moment of inertia of the loading machine (Jext), both in relation to the motor shaft and the speed of rotation and the load, speed of rotation and cyclic duration factor for each speed of rotation in question. For example: S8 – J_M = 0.5 kgm² J_{ext} = 6 kgm² 16 kW 740 rpm 30 % / 40 kW 1460 rpm 30 %

The standard cycle time for the intermittent duty types (S3 to S8) is a minimum of 10 minutes (section 5.4 in EN 60034-1).

	S9
 	**Duty with non-periodic load and speed variations** A duty in which load and speed generally change within the permissible operating range. This duty includes frequently applied overloads that may greatly exceed the full loads. The appropriate designation is S9. For this duty type, a constant load appropriately selected and based on duty type S1 is taken as the reference value (M_{ref}) for the overloading.
	S10
 	**Duty with discrete constant loads** A duty consisting of not more than four discrete values of load (or equivalent loading), each value 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 rest and de-energised windings).

The corresponding designation is S10, supplemented by the related variable $p/\Delta t$ for the particular load and its application time, as well as the related variable TL for the relative service life expectancy of the insulation system. The reference value for the thermal service life expectancy is the thermal service life expectancy as measured for continuous running duty and taking into account the permissible temperature rise limit values in accordance with duty type S1. The load must be designated with the letter r for time at rest and de-energised.
For example: S10 $p/\Delta t = 1.1/0.4$, 1/0.3, 0.9/0.2, r/0.1, TL = 0.6
The numerical value of TL should be rounded to 0.05.
For this duty type, a constant load appropriately selected and based on duty type S1 should be taken as the reference value for the specific loading.
Note:
The discrete values at load will usually be equivalent to continuous running duty based on integration over a period of time. It is not necessary for each load cycle to be exactly the same, only for each load within a cycle to be maintained for sufficient time for thermal equilibrium to be reached, and for each load cycle to be capable of being integrated to give the same thermal life expectancy.

20 Continuous running duty S1

In continuous running duty, the ***state of thermal equilibrium*** is reached by definition – at least 1 ... 6 h is necessary to achieve this depending on the size and ventilation of the motor (see Part VII). Electric motors and geared motors are usually rated and offered for continuous running duty S1, although for many
applications – particularly materials handling – this duty type is not typical.
For this reason the Danfoss Bauer catalogue CD offers a choice between the duty types S3-60 % and S6-60 % for S1; with the same gear unit size – that is, the same mechanical security – and a corresponding motor size these can in some ways offer considerable cost benefits (**Figure 20.1**). The S6-60 % duty type is common if a conveying system is fed intermittently or by hand (**Figure 20.2**).

Figure 20.1
Price comparison (RPS) for geared motors with rated outputs P_N and speed approx. 100 r/min, BF = 1
S1
for continuous running duty
S3/S6-60 %
for intermittent periodic duty or continuous running duty with 60 % ED intermittent loading

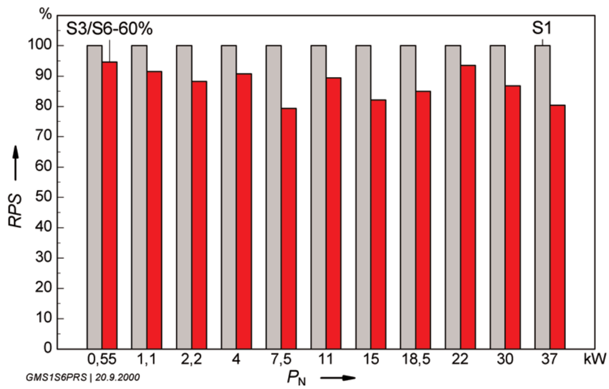


Figure 20.2
Example of application for the S6-60 % duty type: Drum motor for removing intermittently extracted excavation materials from a dredger

21 Short-time duty S2

The diagram in **Figure 21** shows how the heat generation in the winding would rise with increased relative loading P/P_N = 1 / 1.5 / 2 / 4. A higher load (heat loss) would result in a higher end temperature rise Θ_{max} in continuous running duty S1; the increase in heating must therefore be kept within the permissible limits by restricting the time. The diagram shows that the more the machine is overloaded, the shorter the permissible operating hours for S2.

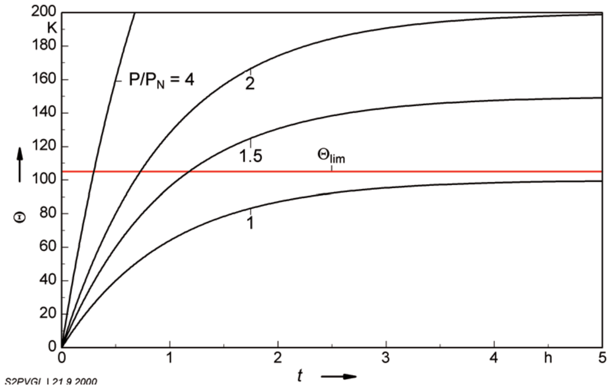


Figure 21
Variation of the temperature increase at different relative levels of utilisation
P/P_N = 1, 1.5, 2 and 4
Θ_{lim} – Maximum temperature rise for temperature class F

The ***increase in output*** as S2 times become shorter is naturally limited by the maximum torque that can be reached. Relatively small machines (e. g., less than 1 kW) usually have relatively low breakdown torques and high rated-load slip; their S2 utilisation cannot be increased very much even with a "harder" winding design (higher flux density). In this case magnetic saturation is the limiting factor.
Medium-sized and larger machines produce relatively high breakdown torques even in the S1 design and for that reason they can be correspondingly highly overloaded in the S2 duty type. In the case of special windings (higher flux density) the ***utilisation factor*** can be increased to about 2.
The following factors represent a guide value for 4-pole motors, which can also indicate other values depending on the design.

Motor type	D05 to D08	D09 to D11	D13 to D18	DNF22 to DNF28
S2 – 5 min	1.6	2.0	2.3	2.3
S2 – 10 min	1.25	1.6	1.7	2.2
S2 – 30 min	1.03	1.15	1.25	1.4
S2 – 60 min	1.0	1.1	1.1	1.15

Marked cells: With special winding

22 Intermittent periodic duty S3 and continuous running duty with intermittent loading S6

Usually the following are given for the factor of increased output f_{Sx} at a reduced duty cycle ED:

for S3 : $f_{S3} = \sqrt[3]{\frac{100}{ED}}$ **for S6:** $f_{S6} = \sqrt{\frac{100}{ED}}$

Relatively high S3/S6 outputs arise which are not usually fully utilised. The table contains guide values for 4-pole motors which can vary according to design. For S6 the saturation-based no-load heating limits any increase in the breakdown torque and therefore also limits the rated output.

Motor Type⇨	D04 to D08		D09 to DNF280	
⇩ ED	S3	S6	S3	S6
15 %	1.6	1.3	1.8	2
25 %	1.5	1.3	1.6	1.8
40 %	1.3	1.3	1.4	1.15
60 %	1.2	1.3	1.2	1.3

Marked cells: With special winding

The current cannot be used as a measurement of heating for duty types S2, S3 and S6; current-dependent delayed thermal over-current relays are therefore only suitable as a protection against blocking caused by the rotor stalling. The ***operating hours*** or the ***winding temperature*** must be monitored.
The running time for duty type S2 is often limited in any case: Factory gates, shutters, hoists are examples of this type of application.
The running time and duration of rest periods must otherwise be monitored. Thermal motor protection (TMP) using thermistors is another reliable method.
For duty types S3 and S6 monitoring the time is too complicated, so ***TMS (thermal motor protection)*** provides the protection instead.

23 Intermittent switched periodic duty S4

This duty type needs to be checked through bearing in mind:

- ☐ Cyclic duration factor
- ☐ Number and type of switching operations (e. g., starting, reversing, pole-switching)
- ☐ Mass moment of inertia (*FI*)
- ☐ Load-torque at run-up
- ☐ Utilisation in stationary operation.

For details see the Danfoss-Bauer book “Starting, braking and positioning with three-phase cage induction motors”.

V MOTOR DESIGN STANDARDS

24 Degree of protection (IP Code)

European standard EN 60529 concerns the technological advancement of a designation system which was introduced in Germany in 1934 and which was subsequently incorporated into various national and international standards. Full information can be found in special publication SD 101 E “IP degrees of protection” and in the Danfoss-Bauer book “Protective measures for three-phase geared motors”.

24.1 Designating the standards

International standard	IEC 60529 (1989), 2nd edition
European standard	EN 60529 : 1991 + A1 : 2000
German standard	DIN EN 60529 (VDE 0470 Part 1) : 2000

24.2 IP Code arrangement

Alphanumeric code for the degree of protection provided by an enclosure:

IP 2 3 C M

Code letters
International Protection

First code number
Numerals 0 to 6 or letter X

Second code number
Numerals 0 to 8 or letter X

Additional letter (optional)
Letters A, B, C, D

Supplementary letter (optional)
Letters H, M, S, W

Where a code number is not required to be specified, it shall be replaced by the letter X. Additional letters and/or supplementary letters may be omitted and do not require replacement. If more than one supplementary letter is used, alphabetical order shall be observed.
If an enclosure has various degrees of protection for the various possible assembly arrangements, the degrees of protection which are affected and are assigned to the specific assembly arrangements must be specified in the manufacturer‘s instructions.

24.3 Meaning of the IP Code

Element	Numerals or letters	Meaning for the protection of the machine	Meaning for the protection of persons
Code letters	**IP**	–	–
First code number		Against penetration of solid foreign bodies	Against access to hazardous parts with
	0	(unprotected)	(unprotected)
	1	≥ 50 mm in diameter	Back of the hand
	2	≥ 12.5 mm in diameter	Finger
	3	≥ 2.5 mm in diameter	Tool
	4	≥ 1.0 mm in diameter	Wire
	5	Dust-protected	Wire
	6	Dust-tight	Wire
Second code number		Against penetration of water, with harmful effects	
	0	(unprotected)	–
	1	Vertical dripping	–
	2	Dripping (15° angle)	–
	3	Spraying water	–
	4	Splashing water	–
	5	Water jet	–
	6	Powerful water jet	–
	7	Temporary immersion in water	–
	8	Permanent immersion in water	–
Additional letter (optional)			Against access to hazardous parts with
	A	-	Back of the hand
	B	-	Finger
	C	-	Tool
	D	-	Wire
Supplementary letter (optional)		Supplementary information specific to	
	H	High-voltage equipment	–
	M	Motion during water test	–
	S	Stationary during water test	–
	W	Weather conditions	–

24.4 Optional suffix letter for protection against access

In the first edition of IEC 60529 and in DIN 40050, high degrees of protection against access had been linked to a correspondingly ***small opening width***, e. g. high degrees of protection against foreign objects. This specification resulted in unnecessary complications for apparatus installed in clean rooms which needs ample ventilation outlets and which, if the internal live parts are spaced correctly, can be protected from access.
The second edition offers the opportunity to mark this ***protection against access, achieved using spacing or guards***, in the form of suffix letters A, B, C or D. This suffix letter can be used if the degree of protection against access is higher than that indicated by the first code number, or if there is no need for a protection rating for protection against ingress of foreign objects to be indicated. Use of this expansion of the code numbers for IP degree of protection in product standards is entirely at the discretion of the Standards Committees.
The national and international committees responsible for degrees of protection for electrical machines decided not to use this suffix letter in their product standard - i.e. in EN 60034-5 (VDE 0530 Part 5) and in IEC 60034-5: ***Protection against access is most commonly attained on electrical machines by limitation of the opening widths and can therefore be described by the first code number of an IP code comprising two numerals***. Other product committees, too, have hardly used the suffix letter option.

24.5 Frequently used degrees of protection for electrical machines

From the multitude of combination options to protect against access and against water, a series of typical combinations have been established. The following table offers an overview of frequently used IP degrees of protection (compare with Appendix A from the previously valid edition of EN 60034 5). The new edition of EN 60034-5 also includes the expensive IP6X dust protection.

2nd code number ⇨	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1st code number ⇩									
0									
1			IP12						
2		IP21	IP22	IP23					
3									
4					IP44				
5					IP54	IP55			
6						IP65	IP66		IP68

25 Methods of cooling (IC Code)

Alongside the “IP Code” for the degree of protection and the “IM Code” for the type and mounting arrangement, a new IC Code designates the cooling methods. This data is so important in terms of safety for the designated use that planners and those using electrical machines want the IC Code to be present both in the documentation and on the rating plate.

25.1 Origins of the designation system

The close relationship between the degree of protection and cooling methods was recognised as early as the first edition of Standard VDE 50 for the “Kurzzeichen für Schutzarten elektrischer Maschinen [Symbols for electrical machinery degrees of protection]” in 1934, and the basic diagram (**Figure 25.1**) shows a machine with intake air and exhaust air ducts (pipe connection). For decades, these degrees of protection and cooling methods have been designated as IP33R.

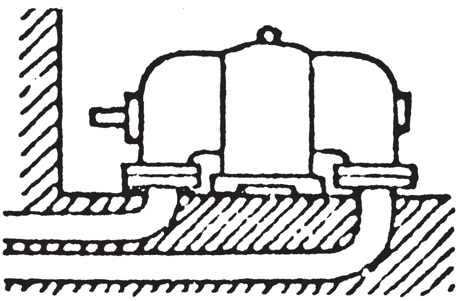


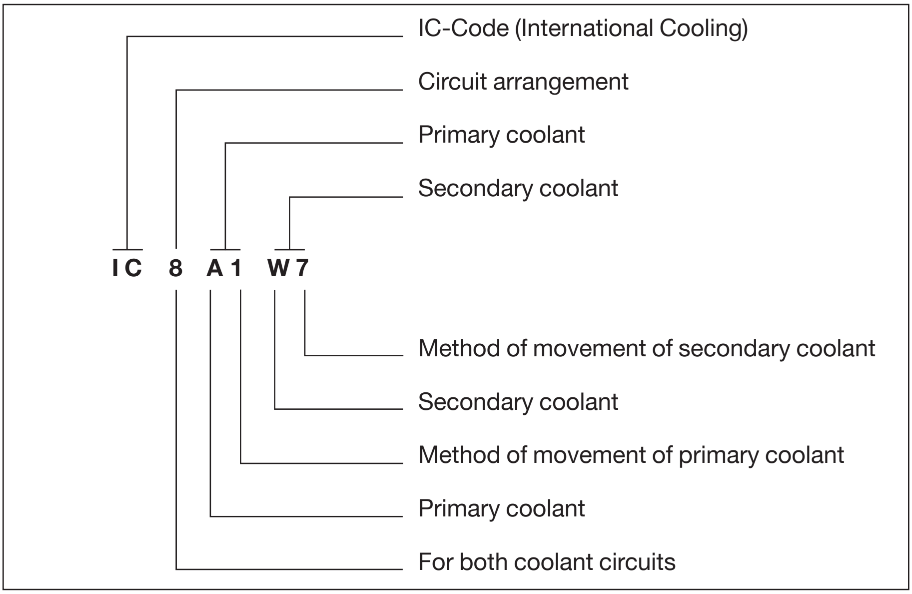
Figure 25.1
Basic diagram of an open-circuit air-cooled machine with a pipe connection for intake and exhaust air ducts

Degree of protection IP33R in accordance with VDE 50

At the end of the 1980s, work began in IEC SC 2H, with significant German contribution, on a revision of the system, which in 1991 finally led to a second edition of the IEC Standard:

- IEC 60034-6
  Rotating electrical machines
  Part 6: Methods of cooling (IC Code)
  The harmonised translation appeared in November 1993 as a European Standard
- EN 60034-6: 1991
  This was adopted in August 1996 as a German Standard as
- DIN EN 60034-6 (VDE 0530 Part 6)
  Rotating electrical machines
  Part 6: Classification of cooling methods (IC Code)

25.2 Complete designation system



25.3 Simplified designation system

The standard provides a simplified edition of the designation system by allowing the omission of:

- ☐ Code letter A for the frequently used coolant, air
- ☐ Code number 7 for the frequently used movement of the secondary coolant, water, through separate, independent assemblies.

The example given above can be reduced to **IC 81 W.**

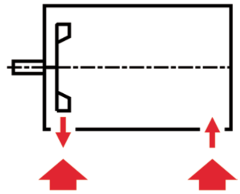
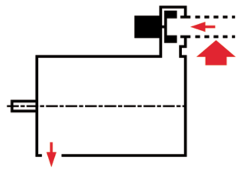
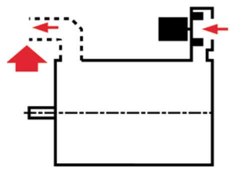
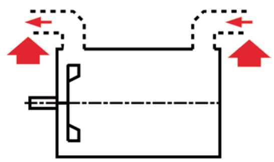
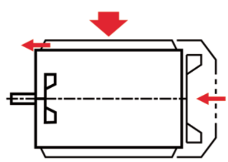
The majority of small and medium-sized machines uses air as both a primary and secondary coolant: This takes the form of closed, surface-ventilated machines for the internal airflow and for the external axial air flow. In this case, the complete designation IC 4A1A1 is reduced to read IC 411.
The simplified, and most commonly used, designation can then be identified by two or three code numbers (without letters) or by a code number at the end of the designation.

25.4 Code number for cooling circuit arrangement

Code number	Brief description	Example
0	Free cooling circuit	Open-circuit cooling
1	Cooling circuit with inlet pipe or inlet duct	Open-circuit cooling with inlet pipe
2	Cooling circuit with outlet pipe or outlet duct	Open-circuit cooling with outlet pipe
3	Cooling circuit with inlet and outlet pipe or duct	Open-circuit cooling with inlet and outlet pipe
4	Surface ventilation	Surface ventilation Ribbed for improved heat exchange
5	Integrated heat exchanger (surrounding coolant)	Surface ventilation Integrated heat exchanger for improved heat exchange
6	Machine-mounted heat exchanger (surrounding coolant)	Surface ventilation Machine-mounted heat exchanger for improved heat transmission
7	Integrated heat exchanger (supplied coolant)	Water cooling Integrated heat exchanger
8	Machine-mounted heat exchanger (supplied coolant)	Water cooling Machine-mounted heat exchanger
9	separately mounted heat exchanger (surrounding or supplied coolant)	Water cooling Separate heat exchanger

The code number for the cooling circuit arrangement is also significant for the design principles of the machine. Code numbers 0 to 4 are mainly used for small and medium-sized machines.
The following table shows the relevant symbols for these first relevant code numbers.

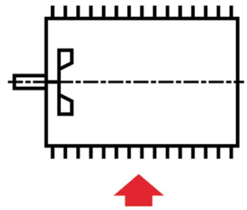
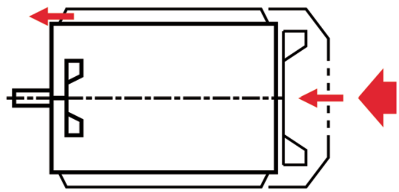
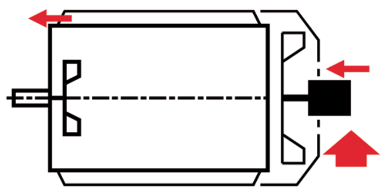
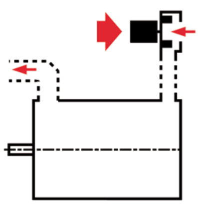
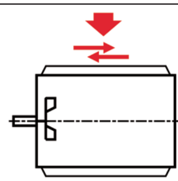
25.4 Code number for cooling circuit arrangement

Code numbers for cooling circuit arrangement	Frequently used design
IC0X	
IC1X	
IC2X	
IC3X	
IC4X	

Frequently used cooling circuit arrangements
(Symbol indicated by an arrow ↓)

25.6 Code numbers for the method of movement of the coolant

The following examples are used particularly frequently or are particularly typical of the method of movement of the coolant
(Symbol indicated by an arrow ↓):

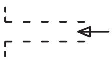
Code number Frequently used design for the method of movement	
ICX0	
ICX1	
ICX6	
ICX7	
ICX8	

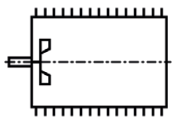
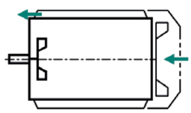
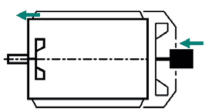
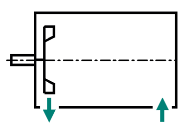
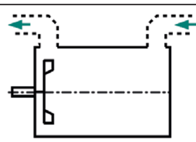
25.7 Commonly used designations

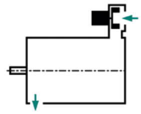
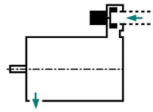
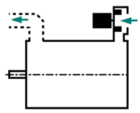
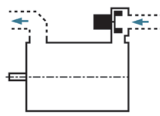
Some of the commonly used cooling methods and their newly-assigned IC Codes are shown in the following selection from a table. To help with “translation”, the former code in accordance with the first edition of IEC 34-6 is also listed. In accordance with IEC 60034-6, the following symbols are used:

 **integral or machine-mounted dependent fan**

 **independent circulation component**

 **duct or pipe, not part of the machine**

IC Code in accordance with IEC 60034-6 2nd edition		Basic diagram	Code in accordance with IEC34-6 1st edition
Simplified	Complete		(Formerly)
IC 410	IC 4A1A0		IC 40
IC 411	IC 4A1A1		IC 41
IC 416	IC 4A1A6		IC 46
IC 01	IC 0A1		IC 01
IC 31	IC 3A1		IC 31

IC 06	IC 0A6		IC 06
IC 16	IC 1A6		IC 16
IC 26	IC 2A6		IC 26
IC 36	IC 3A6		IC 36

Selection of frequently used IC cooling methods for electrical machines

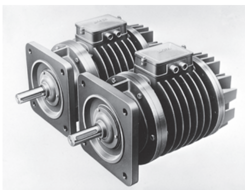
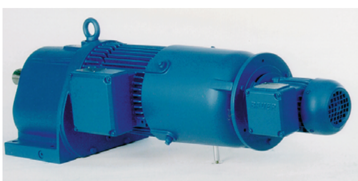
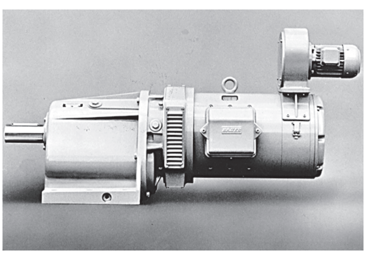
25.8 Designation on the rating plate

There is currently no specification (e. g. in IEC 60034-1 or EN 60034-1) which states that there must be an IC designation on the rating plate. With certain cooling methods, however, it may be necessary to document by way of the appropriate
IC Code data that additional system measures are necessary when setting up and connecting the machine. This is true, for example, of machines with pipe connections or if compulsory components (e. g. fan assemblies) are supplied separately. Depending on the method of cooling, it may be necessary to supply additional technical data (e. g. coolant volumetric flow, pressure drop in the machine), in the accompanying documentation at least.
Since the machine can only be put to its designated use if the relevant instructions are available, and the manufacturer or installer has certain duties in terms of product liability, the IC Code is first used in documentation such as catalogues, and mounting and operating instructions, and soon after appears on the rating plate – even if it is only in anticipation of an expected designation in specification or standards.

25.9 Summary

The IC Code for the cooling methods of electrical machines currently in use according to IEC 60034-6 forms a simple means of communication between manufacturers on the one hand and engineers or operators on the other. After an unavoidable settling in period, it is certain that the code will soon be used by both manufacturers and users of electrical machines. The tables and explanations in this section have been simplified to comply with those in common use. They should not and cannot replace reading the whole version.

25.10 Examples from the Danfoss-Bauer manufacturing programme

IC410		Figure 25.10.1 Non-ventilated Totally enclosed AC roller-table motor
IC411		Figure 25.10.2 Self-ventilated Totally enclosed AC cage motor with mounted bevel-gear unit
IC416		Figure 25.10.3 Independently ventilated Completely enclosed three-phase cage motor with mounted helical-gear unit
IC06		Figure 25.10.4 Independently ventilated open-circuit air-cooled DC shunt motor with mounted helical-gear unit

26 Mounting arrangement (IM Code)

One of the important basic standards for electrical machines was republished in June 1993 as
EN 60034-7
Rotating electrical machines – Classification of types of construction and mounting arrangements (IM Code).

The first standards for the mounting arrangements of electrical machines appeared in Germany as early as 1924 with VDE 2950. The abbreviation, accepted and used in many countries by way of DIN 42950, was adopted in 1972 as “Code I” in the international standard IEC 60034-7. A more extensive, systematically designed “Code II” has not yet been generally accepted. The new standard is based on

- ☐ ***IEC 60034-7 (2nd edition 1992) Rotating electrical machines***
  Part 7: Classification of types of construction and mounting arrangements (IM Code)
- ☐ ***German version: DIN EN 60034-7 / VDE 0530 Teil 7 : 1996***

Neither IEC 60034-1 nor DIN EN 60034-1 (VDE 0530 Part 1) currently contains any regulations for using the IM designation on machine rating plates. However, the installation type must be suitably documented to provide a definition of the “intended use”. This should preferably be done on the rating plate, but at least in the accompanying documentation.
The concepts of “type of construction” and “mounting arrangement” had already been delimited against one another in the previous standard, as the standard deals, on the one hand, with design features (types of construction, such as foot, flange, pedestal bearing) and, on the other hand, a machine of the same “type of construction” can be used in different “mounting arrangements”, such as B3, B6, B7, V5, V6.

This distinction should also be made in common usage.

26.1 Coding system

26.1.1 DIN 42950 (obsolete) and Code I in the current standards

A – Machines without bearings, horizontal mounting (obsolete)
B – Machines with endshields, horizontal mounting
C – Machines with endshields and pedestal bearings, horizontal mounting (obsolete)
D – Machines with pedestal bearings, horizontal mounting (obsolete)
V – Machines with endshields, vertical mounting
W – Machines without endshields, vertical mounting (obsolete)

26.1.2 Code II

IM 2 01 1

Code letters – **IM**
International Mounting

First code numeral (0 ... 9) – **2**
Type of construction

Second and third code numerals (0 ... 99) – **01**
Type of mounting and arrangement

Fourth code numeral (0 ... 9) – **1**
Type of shaft extension

26.1.3 Significance of the first code numeral in Code II

The significance of the second and third numeral depends on the first numeral with which they are associated, ie varying logic from table to table.

0 – (not allocated)
1 – Foot-mounted machines with endshield bearing(s) only
2 – Foot- and flange-mounted machines with endshield bearing(s) only
3 – Flange-mounted machines with endshield bearing(s) only, with a flange as part of the endshield
4 – Flange-mounted machines, with endshield bearing(s) only, with a flange not as part of the endshield, but as part of the enclosure or another component
5 – Machines without bearings
6 – Machines with endshield bearing(s) and pedestal bearing(s)
7 – Machines with pedestal bearing(s) only
8 – Vertical machines of construction not covered by first numerals 1 to 4
9 – Machines with special mounting arrangements

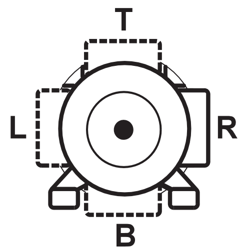
26.1.4 Significance of the fourth code numeral in Code II

0 – No shaft extension
1 – One cylindrical shaft extension
2 – Two cylindrical shaft extensions
3 – One conical shaft extension
4 – Two conical shaft extensions
5 – One flanged shaft extension
6 – Two flanged shaft extensions
7 – Flanged shaft extension (D-end) and cylindrical shaft extension at N-end
8 – (not allocated)
9 – Other arrangements

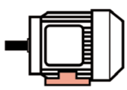
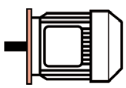
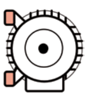
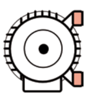
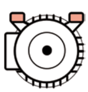
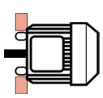
26.2 Terminal box location

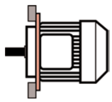
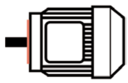
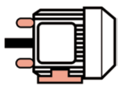
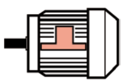
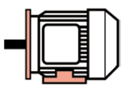
Amendment A1 (1999) of the standards referred to above now specify the location of the terminal box when looking at the shaft end and feet or drain opening (on flanged design) in the “6 o’ clock” position:

Code letter	Terminal box location	
R	right	3 o’ clock
B	bottom	6 o’ clock
L	left	9 o’ clock
T	top	12 o’ clock
(none)	not specified	

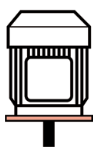
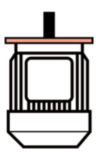


26.3 Machines with endshields, horizontal mounting arrangement

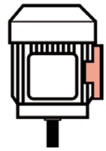
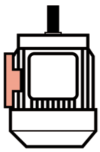
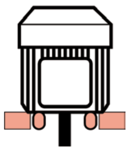
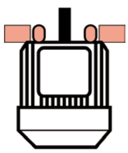
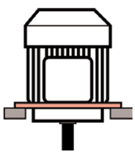
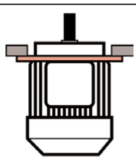
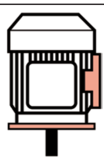
Sketch	Designation		
	Code I	Code II	DIN 42950
	**IM B3**	IM 1001	B3
	**IM B5**	IM 3001	B5
	**IM B6**	IM 1051	B6
	**IM B7**	IM 1061	B7
	**IM B8**	IM 1071	B8
	**IM B9**	IM 9101	B9

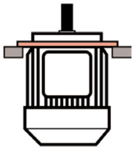
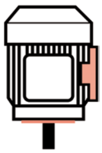
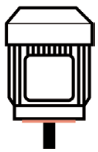
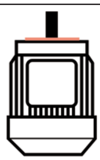
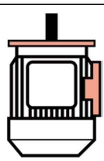
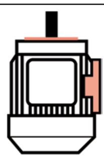
Sketch	Designation		
	Code I	Code II	DIN 42950
	**IM B10**	IM 4001	B10
	**IM B14**	IM 3601	B14
	**IM B15**	IM 1201	B15
	**IM B20**	IM 1101	B20
	**IM B35**	IM 2001	B3 / B5

26.4 Machines with endshields, vertical mounting arrangement

Sketch	Designation		
	Code I	Code II	DIN 42950
	**IM V1**	IM 3011	V1
	**IM V3**	IM 3031	V3

26.4 Machines with endshields, vertical mounting arrangement

Sketch	Designation		
	Code I	Code II	DIN 42950
	**IM V5**	IM 1011	V5
	**IM V6**	IM 1031	V6
	**IM V8**	IM 9111	V8
	**IM V9**	IM 9131	V9
	**IM V10**	IM 4011	V10
	**IM V14**	IM 4031	V14
	**IM V15** Amendment A1:1999	IM 2011	V1 / V5

Sketch	Designation		
	Code I	Code II	DIN 42950
	**IM V16**	IM 4131	V16
	**IM V17** Amendment A1:1999	IM 2111	V18 / V5
	**IM V18**	IM 3611	V18
	**IM V19**	IM 3631	V19
	**IM V35** Amendment A1:1999	IM 2031	V3 / V6
	**IM V37** Amendment A1:1999	IM 2131	V19 / V6

27 External mechanical shock (IK Code)

In September 1997 a new IK Code, DIN EN 50102 (VDE 0470 Part 100), was introduced to supplement the IP Code. This classification had until then not been part of German or International standards; according to the introductory paragraph of this new European standard, it is intended to lead to the standardisation of methods for describing the protection of enclosures against external mechanical shock and to be incorporated in the respective product standards coming under the responsibility of the individual technical committees. The letter K is derived phonetically from the French CA = casser = to break.

27.1 Background

In earlier French standards for IP degrees of protection (e. g., NF C 20-010: 1986) there was always a ***third code number*** provided for classifying the mechanical strength of enclosures. As minimum requirements for this aspect of electrical machines are determined in the French installation regulations, the French standardisation specialists were determined that when IEC 60529 : 1989 and the correspondingly harmonised EN 60529 : 1991 were revised, this system of classification would be incorporated into international and regional standards. IEC TC 70 decided against this extension of the IP Code, because, of necessity, other code numbers would have followed (e. g. for protection against corrosion, solar radiation and icing) which would have reduced the willingness of electrical engineers to accept this proven means of communication. Consequently there was a gap in the safety aspect of French standards which was now to be closed by EN 50102 with the independent IK Code, entirely separate from the IP Code. In German and International standardisation, requirements for the mechanical strength of enclosures – in so far as they are necessary – are currently described without using a special designation. For that reason there is no immediate cause to incorporate the IK Code in product standards and installation regulations.

27.2 Scope of application

The standard for the classification of degrees of protection against external mechanical shock to enclosures should only be applied if an IK Code is provided for in the product standard. It also applies to empty enclosures (currently drafted as prEN 60439-6) if the general test requirements are satisfied.

27.3 Structure of the IK Code

	IK	05
Code letters (international mechanical protection)	IK	
Characteristic group of figures (00 to 10)		05

27.4 Meaning of the IK Code

IK Code	IK00	IK01	IK02	IK03	IK04	IK05	IK06	IK07	IK08	IK09	IK10
Impact in J	[1]	0.14	0.2	0.35	0.5	0.7	1	2	5	10	20

[1] – not protected in accordance with the standard

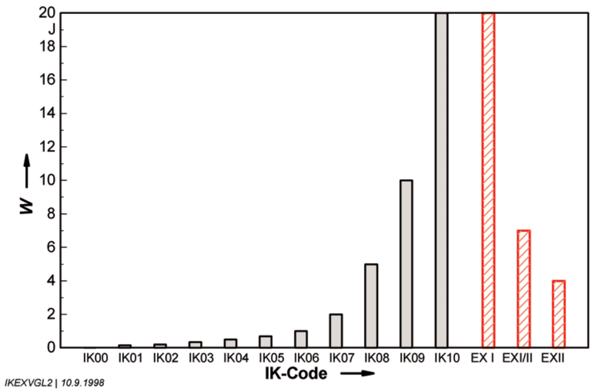


Figure 27.4
Classification of the mechanical impact resistance of electrical machinery in the new IK Code in accordance with EN 50102 by comparison with the specifications for explosion-proof apparatus (EX)

27.5 Conclusion

Mechanical damage caused by external influences and not the electrical machine itself are relatively common. Certain fields of application – mining, woodworking, construction sites – place particularly high demands on motors. The conditions of operation are frequently described as “normal” but the process hides the true nature of the situation: A machine tool does not in itself represent an arduous application but a motor or switch installed in an exposed location can easily be crushed by a forklift truck.

Consequences for the user:
As far as possible electrical apparatust (motors, switchgear and control units) should be arranged so that it is protected against the mechanical influences to be expected from its being used for the purpose for which it is intended. An additional cover can sometimes be more effective and cost-efficient than creating a special design for the machinery.

28 Explosion protection

Electrical installations in areas with potentially explosive atmospheres are subject to special requirements and legislation in practically all industrial nations. In Germany, such installations belong, according to the ***Law on industrial equipment (equipment safety law)*** GSG to the "electrical installation in particularly hazardous areas (installations requiring supervision)" for which the "Regulation concerning electrical installations in potentially explosive atmospheres (ElexV)" et al is intended,

- that the erection, commissioning and modification of such installations requires notification or permission,
- that such installations must satisfy special requirements and
- that such installations are subject to initial inspection before commissioning, routine periodic inspections (continuous supervision) and inspections as a consequence of instructions from the authorities.

All the work described must be done by skilled personell.

Detailed descriptions may be found in our publication SD 3.. "Explosion protection for geared motors".
The discussions below principally deal with the regulations in accordance with EC Directive 94/9/EC (ATEX 100a) applicable since 1996 and mandatory from 01.07.2003 in the EC.

28.1 EC directives

The member states of the European Community (EC) undertook, in the Treaties of Rome, to reduce barriers to trade. The differing design and testing regulations related to explosion-proof electrical apparatus and the fact that approval by a national test house is sometimes required by law were just such barriers to trade. The "Directive of the Council on the harmonisation of the member states' legislation relating to the general provisions for the construction of certain types of protection for electrical apparatus for use in potentially explosive atmospheres" (in short: The EC frame directive) lays down that the member states of the EC may not prohibit the free trade in goods, if electrical apparatus comply with the European standards. The details of certification and marking are laid down in the relevant individual directives. Test certificates issued by the following testing authorities should be mutually recognised within the EC:

BE	DK	DE	ES	IT	FR	GB	NL	FI	AT	SE
ISSeP	DEMKO	PTB; BVS/ DMT	LOM	CESI	LCIE INERIS	EECS SCS	KEMA	VTT	BVFA TÜV-A	SP

The obligation to recognise test certificates issued by national test centres currently only officially applies to EC member states, and not to the other CENELEC states (see also section 28.4.1).
A full up-dated list of ATEX notified bodies is offered via www.europa.eu.int

Implementation of the EEC Treaty	
Harmonisation of legislation for the creation of an internal market	Social provisions for the improvement of the working environment
Article 100 a ⇨ **ATEX 100 a**	Article 137 ⇨ **ATEX 137** (previously ATEX 118a)
Construction	Installation and operation
Directive 94/9/EC	**Directive 1999/92/EC**
Equipment and protective systems intended for use in potentially explosive atmospheres	Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres

28.2 Certification

Test certificates were issued if the “Regulations for explosion-proof electrical equipment” VDE 0171/2.61 were complied with.
Certificates of Conformity are / were issued when there is compliance with the relevant harmonised European standards “Electrical apparatus for potentially explosive atmospheres” EN 50014/VDE 0170/0171 Part 1 to EN50020/VDE 0170/0171 Part 7.
Certificates of Inspection were/are issued where at least the equivalent level of safety is ensured by some other means.
EC declarations of conformity are issued by a “notified body” in the case of compliance with the basic safety and health requirements for the design and construction of equipment for intended use in potentially explosive atmospheres in accordance with Appendix II of Directive 94/9/EU. It has been possible to issue
EC type approval certificates of this type since 01.04.1996. From 01.07.2003, only apparatus with an EC type approval certificate may be sold for use in potentially explosive atmospheres.

The following are to be noted in the ***installation of electrical systems***:
- ☐ EN 60079-14 (VDE 0165 Part 1): Electrical apparatus for explosive gas atmospheres – Part 14: Electrical installations in hazardous areas (other than mines).
- ☐ EN 50281-1-2 (VDE 0165 Part 2): Electrical apparatus for use in the presence of combustible dust – Part 1-2: Selection, installation and maintenance.

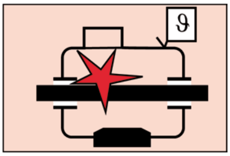
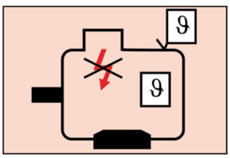
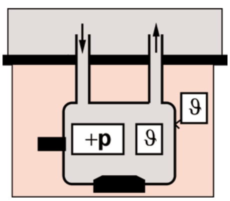
28.3 Types of protection

The following types of protection are customary for electrical machines:
- ☐ Increased safety “e”
- ☐ Flameproof enclosure “d”
- ☐ Pressurised enclosure “p”
- ☐ Non-sparking “n”
- ☐ Dust ignition proof “tD”.

Their application depends on the nature of the explosible atmosphere and the probability of its occurrence (zone). Within their application group, types of protection “e”, “d” and “p” are equivalent in accordance with the standards and regulations (**Table 28.3.1**). In practical application, however, there is a different rating system, which is in part technically or economically justified, but in part may also be explained as a result of specific operating experience or (for example in North-American regions) of decades of different standardisation customs.

Ex-hazard	**Zone**	Permissible machinery	Associated regulations	
			Design	Installation
Combustible dust	20	Motors not permitted	–	–
	21	EEx tD + IP65	EN 50281-1-1 (VDE 0170/0171 Part 15-1-1)	EN 50281-1-2 (VDE 0165 Part 2)
	22	Motor and terminal box IP54	EN 50281-1-1 (VDE 0170/0171 Part 15-1-1)	EN 50281-1-2 (VDE 0165 Part 2)
Gases and vapours	1	General EEx e II EEx d II EEx p II	EN 50014 EN 50019 EN 50018 EN 50016	DIN EN 60079-14 (VDE 0165 Part 1) IEC 60079-14
	2	EEx nA II T3	DIN EN 50021 (VDE 0170/0171 Part 16)	DIN EN 60079-14 (VDE 0165 Part 1) IEC 60079-14
Fire-damp		EEx d I	EN 50014 EN 50018	DIN VDE 0118
Explosive materials		Motor IP44 terminal box IP54	–	DIN VDE 0166

Table 28.3.1 Types of protection of electrical machines as a function of the type of potentially explosive atmosphere

	Principle	Type of protection
d		**Flameproof enclosure** A type of protection in which the parts which can ignite an explosive atmosphere are placed in an enclosure which can withstand the pressure developed during an internal explosion of an explosive mixture and which prevents the transmission of the explosion to the explosive atmosphere surrounding the enclosure. **Typical application:** Inverter-fed cage motors, DC. motors
e		**Increased safety** A type of protection in which additional measures are applied so as to give increased security against the possibility of excessive temperatures and of the occurrence of arcs or sparks inside or on external parts of the electrical apparatus which does not produce arcs or sparks in normal service. **Typical application:** Three-phase cage motors. [IEV 426-08-01]
p		**Pressurised enclosure** A type of protection of electrical apparatus in which safety is achieved by means of a protective gas maintained in a pressure above that of the surrounding atmosphere. **Typical application:** Large electrical machines of all kinds

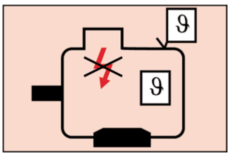
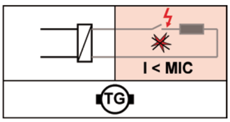
	Principle	Type of protection
nA		**Restricted breathing or non-sparking Zone 2 apparatus** A type of protection applied to electrical apparatus such that, in normal operation and in certain abnormal conditions specified by the standard, it is not capable of igniting a surrounding explosive atmosphere. **Typical application:** Three-phase cage motors
i		**Intrinsic safety** A circuit in which any spark or thermal effect produced in the conditions specified in the standard, which include normal operation and specified fault conditions, is not capable of causing ignition of a given explosive atmosphere. **Typical application:** Tacho generators

Figure 28.3.2 Principle of the types of protection applicable for electrical machines

28.4 International explosion protection regulations

Explosion protection is regulated through ***national standards and laws*** in most industrial nations. When exporting, therefore, it is necessary to check carefully whether a motor manufactured and inspected in accordance with the European standard is approved.

28.4.1 European regulations

Considerable harmonisation of European standards in the field of explosion protection was achieved relatively early in CENELEC. The certificates issued by the accredited test houses notified by the EC should be mutually recognised in the EC (see section 28.1). The obligation to recognise test certificates issued by national test centres currently only officially applies to EC member states, and not to the other CENELEC states. PTB test certificates are usually recognised in ***Scandinavia*** and ***Eastern Europe***. In the past, additional acceptance by the SEV (Schweizer Elektrotechnischer Verein - Swiss Electrotechnical Assocation) and approval by the Eidgenössische Starkstrominspektorat was mandatory in ***Switzerland***; this requirement has now been dropped. EC type declarations of conformitiy (ATEX) are recognised.

28.4.2 North American regulations

The following types of protection are specified in North American regulations:

Class I	**Division 1:**	USA-NEC	Article 501-8 a)
		CANADA-CEC	Section 18-112

Flameproof enclosure, ***with*** Certificate or Approval.

Class I	**Division 2:**	USA-NEC	Article 501-8 b)
		CANADA-CEC	Section 18-164

Cage motors without sliding contacts (non-sparking) in normal non-explosion proof design, ***without*** Certificate or Approval, ***but with brakes*** as for Division 1.

Class II	**Division 1:**	USA-NEC	Article 502-8 a)
		CANADA-CEC	Section 18-210

Dust ignition proof (DIP), ***with*** Certificate or Approval.

Class II	**Division 2:**	USA-NEC	Article 502-8 b)
		CANADA-CEC	Section 18-260

Totally enclosed (dust-proof enclosed), ***without*** Certificate or Approval; with inherent thermal motor protection in Canada, ***but brakes*** as for Division 1.

Motors in type of protection "e" or in degree of protection IP65 which is usual for Danfoss Bauer, largely ***technically*** comply with the North American requirements on "non-sparking" for applications in Class I, Div. 2 or Class II, Div. 2, as long as they have no attachments or installed components which issue sparks or can heat up uncontrollably (thermostats, anti-condensation heating, brakes etc).
Since even North American users are frequently unclear as to which regulations are to be applied in Class I, Division 2, extracts from NEMA MG2, 3.5, are quoted below:
"Open motors or motors without an explosion-proof enclosure are permissible, as long as they have no brushes, switches or similar spark-generating components. The user may select drives of this type and propose them to the local authorities for approval. As the enclosure is not explosion-proof, the user must take into consideration the temperatures of the internal and external surfaces to which the surrounding atmosphere has access."
The standard gives guide values for the maximum temperatures of the stator winding and the cage to be expected as a function of the insulation class (temperature class).

28.4.2 North American regulations

Type of protection “d” largely corresponds technically to the North American requirements on “flameproof” for Class I, Division 1, as long as the terminal box is provided in type of protection “d” and a flameproof cable entry is used at the site of installation.
Further classification of the potentially explosive atmosphere is to be noted:

Class I	–	**Gases and vapours**			
		Group	A	corresponds to	IIC
			B		IIB
			C		IIA
			D		IIA
Class II	–	**Dusts**			
		Group	E	conductive $R < 10^5\ \Omega \cdot cm$	
			G	non-conductive $R > 10^5\ \Omega \cdot cm$	
Class III	–	**Textile fibres**			

Table 28.4.2 Classification of the potentially explosive atmospheres according to the NEC

In addition to the national North American regulations listed above, the newly adopted NEC Article 502 recently also permits testing and approval in accordance with the IEC 60079 series of international standards.
In the ***USA***, some requirements going beyond the IEC are made for the types of protection “e” and “d”, and these then demand additional testing by UL or FMR.
In ***Canada*** a certificate from a national test house (e.g. PTB or BVS) is recognised, but it must have a CSA test mark added to it.

NEC 505	Division 1		Division 2
IEC / CENELEC	Zone 0 Zone 20	Zone 1 Zone 21	Zone 2 Zone 22

29 Regulations outside Germany

When electrical motors are exported from Germany, the customer frequently requires compliance with the regulations valid in the destination country. A motor constructed in accordance with EN 60034-1 (DIN VDE 0530 Part 1) “Rotating electrical machines; rating and performance” complies in electrical terms with the standard issued by the International Electrotechnical Commission (IEC 60034-1, Rotating electrical machines; Part 1: Rating and performance), which is recognised by all important industrial nations.
Furthermore, Danfoss-Bauer drives comply with the following points:

29.1 Rating plate with international symbols

The abbreviations used on the rating plate are internationally understood, so that one important prerequisite for the commissioning of the drive is met at the installation location, whether the motor is exported directly or as a component.

Figure 29.1.1
Rating plate
for a three-phase AC geared motor

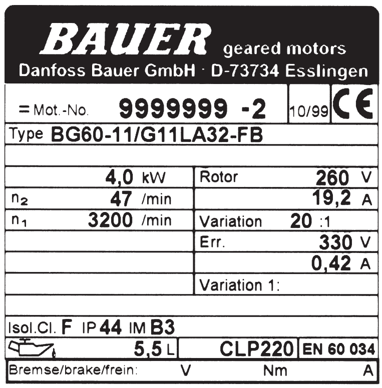
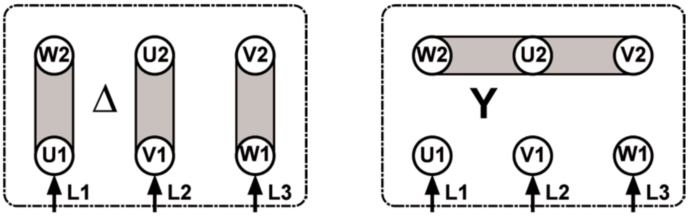


Figure 29.1.2
Rating plate
for a DC geared motor

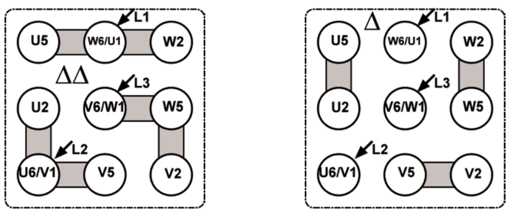
29.2 Terminal marking

The terminal markings for electrical machines were standardised internationally as early as 1972 in IEC 60034-8. The system was introduced into Germany in DIN VDE 0530 Part 8; it will also appear as EN 60034-8 following the revision procedure which is currently underway. The connection diagrams for Danfoss-Bauer drives are practically all drafted in accordance with international standards.
Unfortunately, the international standards have not been adopted in North America – different rules apply there, e. g. NEMA MG1-Section I, Part 2 or ANSI C 6.1.



	International / National	North America
Standard	IEC 60034-8 / DIN 42 401	ANSI C 6.1
Mains	L1 - L2 - L3	L1 - L2 - L3
Winding ends	U1 - V1 - W1 U2 - V2 - W2	T1 - T2 - T3 T4 - T5 - T6
Δ	Low mains voltage circuit (e. g. 220 V)	
Y	High mains voltage circuit (e. g. 380 V)	

Figure 29.2.1 International connection diagram for dual voltage winding in the ratio 1: √3 (Δ/Y)



	International / National		North America	
Standard	IEC 34-8 / DIN 42 401		ANSI C 6.1	
Mains	L1 - L2 - L3		L1 - L2 - L3	
Winding ends	U1 - U2	U5 - U6	T1 - T4	T7 - T10
	V1 - V2	V5 - V6	T2 - T5	T8 - T11
	W1 - W2	W5 - W6	T3 - T6	T9 - T12
ΔΔ	Low mains voltage circuit (e. g. 230 V)			
Δ	High mains voltage circuit (e. g. 460 V)			

Figure 29.2.2 International connection diagram for dual voltage winding in the ratio 1: 2 (ΔΔ/Δ)

29.3 Supply frequency

The motor windings must be modified for the 60 Hz supply frequency which is usual in some countries outside Europe. The nominal speed of an asynchronous motor changes with the supply frequency (see section 1.1). If a three-phase induction motor is connected to the incorrect supply frequency – e. g. when testing an installation intended for the USA (60 Hz) in the manufacturer's works (50 Hz) or when a stock motor (50 Hz) is used for a rush export order (60 Hz) – the following rules must be noted:

29.3.1 Connection to a proportionately changed frequency and voltage

If the actual voltage and frequency change proportionately against the design data for the winding design – if, therefore, U/f = is constant – the magnetic flux of the motor remains at the same strength. The magnitude of the torque developed is, thus, unchanged. The speed changes proportionately with the frequency. The rated output available, thus, varies approximately with the frequency, while in the case of frictionally loaded drives, the power consumption also varies proportionally with speed – that is frequency.

For example: Ratings for a geared motor

Output P	= 7.5 kW	Voltage U	=	400 V
Speed n_2	= 200 rpm	Frequency f	=	50 Hz
Torque M_2	= 360 Nm			

It is intended to connect this motor to 460 V, 60 Hz

$$\frac{U}{f} = \frac{400}{50} = \frac{460}{60} \approx \text{const. applies}$$

The following new ratings thus apply:

Output P	= $1.2 \cdot 7{,}5 = 9$ kW	Voltage U	=	460 V
Speed n_2	= $1.2 \cdot 200 = 240$ r/min	Frequency f	=	60 Hz
Torque M_2	= 360 Nm			

Connection to a proportionately varied frequency and voltage is permissible. The modified rated output of the motor corresponds approximately to the modified power requirement, as long as this is predominantly determined by friction.

29.3.2 Connection to higher frequency at identical voltage

Magnetic flux reduces inversely to the frequency, the magnitude of the starting and pull-out torques reducing in a square law with the magnetic flux. The speed increases linearly with the frequency. As the ventilation also improves, most drives may be approved up to the full rated output without thermal hazard, as long as the reduced torque reserve remains adequate. In the case of predominantly frictionally loaded drives it should be noted that the power requirement increases with speed (frequency) so that the incorrectly connected motor is too small by the factor of the inverse frequency ratio.

For example: Ratings for a geared motor

Output P	=	7.5 kW
Speed n_2	=	200 r/min
Torque M_2	=	360 Nm
Voltage U	=	380 V
Frequency f	=	50 Hz

Dieser Motor soll an 380 V 60 Hz angeschlossen werden. Daher gelten folgende neuen Daten:

Output P	=	7.5 kW		
Speed n_2	=	200 · 60/50	=	240 r/min
Torque M_2	=	300 Nm		
Voltage U	=	380 V		
Frequency f	=	60 Hz		
Power consumption P_{60}	=	7.5 · 60/50	=	9 kW

Output available only 7.5/9 = 0.85 times the power requirement, which is approximately equal to 50/60 = 0.85.

Connection to higher frequency with unchanged voltage is not hazardous for the motor, as long as it is noted that the reduced starting and pull-out torque of the motor are some 70 % of the values at 50 Hz and the rated output is some 85 % of the modified power requirement of frictionally loaded drives.

29.3.3 Connection to reduced frequency at identical voltage

Magnetic flux increases in inverse ratio to the frequency. Supersaturation of the solenoid circuit leads to a significant rise in the magnetising current. For this reason, the motor warms up quickly and significantly, even under no-load operation.
A trial run is only permitted briefly under ongoing temperature monitoring and must be halted after a few minutes.

For example: Rated data for a geared motor
Voltage U = 380 V
Frequency f = 60 Hz
Short trial runs only are permitted on a 380 V 50 Hz supply. Section 29.3.1 applies for the use of a transformer for approximately 330 V 50 Hz, as then U/f = constant.

Connection to reduced frequency with unchanged voltage is only permitted briefly under constant temperature monitoring.

29.4 Regulations applied outside Europe

While in most non-European regulations (e. g. including NEMA MG 1 for the USA) recommend compliance, although they do not require it, official approvals are required in some other applications. This is the case for instance for

- ☐ CANADA: CSA Approval in accordance with C 22.2 required
- ☐ INTERNATIONAL SHIPPING: Inspection by British Lloyd German Lloyd or American Bureau of Shipping frequently required
- ☐ EXPLOSION PROTECTION: Certificates of conformity in accordance with EN 50014 to EN 50019 must be recognised in the EC member states in accordance with the EC Directive. In North America special regulations apply.

In the cases listed above, in particular, but also in case of doubt, a binding agreement with the non-European customer regarding any regulations that are to be complied with is recommended.

30 Special considerations for US American electric motors

"An imported headache for US users – 50 Hz apparatus": That was the title of an article in ELECTRICAL APPARATUS, the main specialist journal of the EASA service workshops operating in the field of electrical machine construction and drive system technology in the USA. The article describes in detail how disregarding regulations and normal working practices can delay the commissioning of machines and installations. The fact that, in the USA, there are already "conversion shops" specialising in the conversion of imported electrical machines and installations and that these shops are doing good business, suggests that the problems encountered are not isolated cases. Users in North America appreciate the high status of European special machinery construction. Exporters would be well advised to heed a few basic rules in order to adapt electrical equipment to North American regulations and to the expectations of their customers, so that the commissioning process goes as smoothly as possible.
This section will introduce – without any claim to completeness – some of the main basic rules for electrical machines.

30.1 Main electrotechnical regulations

In North America there exists a series of regulations for electrical machines and installations, which will differ in part from the European and international standards. Special reference is made to the test obligations when exporting to Canada.

NEMA National Electrical Manufacturers Association
Association of electrical equipment manufacturers.
Publishes NEMA Standards MG1 Motors and Generators.
These regulations are not binding but are for the most part adhered to in the USA.

UL Underwriters Laboratories Inc.
Publisher and test agency for equipment for use in areas which affect the safety of persons and installations.
Binding, for example for machinery for use in the home or office and in areas subject to explosion hazards.
Explosion-proof motors must be tested, and must be capable of being tested as individual components.
Built-in motors in equipment for layperson use only have to be capable of being tested with the associated equipment.

NEC National Electrical Code
General installation regulations (comparable with VDE 0100), published by the NFPA (National Fire Protection Association).
Article 430 is primarily concerned with the selection and installation of motors – to a large extent is met by observing NEMA regulations.
Article 500 is concerned with explosion protection and must be strictly adhered to.

ANSI American National Standards Institute (formerly ASA and USASI)
Publisher of American National Standards for basic standards, that are often incorporated into NEMA regulations.

IEEE Institute of Electrical and Electronics Engineers
Publisher of IEEE Standards
Basic standards for electrical engineering parts of which (e. g. determining the efficiency) are incorporated into NEMA regulations.

JIC Joint Industry Conference
Joint association of industrial companies
Publisher of installation regulations, in the case of motors makes reference to NEMA regulations.

30.2 Mains designation and rated voltage

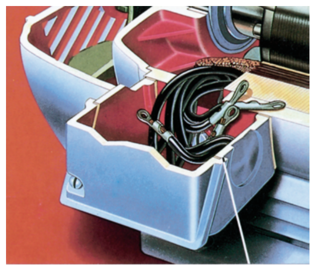
The usual designations in North America are confusing because there are often two, sometimes even three, different sets of voltage information used for one specific network. Column 3 in **Table 30.2** is definitive for the rating plate information on a motor (also in accordance with NEMA MG 10). Voltage information written as 120/208 V, 240/416 V, 277/480 V and 347/600 V is an additional confusion for motor manufacturers: They do not each denote two different three-phase networks but, instead, for example one 3-phase 480 V network with a voltage of 277 V to neutral. It is therefore ***not necessary***, to design the winding to be ***switched*** for two different voltages, e.g. 277 V Δ /480 V Y.
The lack of clarity is most simply and most safely resolved by specifying the three-phase voltage, e. g. 460 V, when ordering the motor and then having this marked on the motor‘s rating plate. 208 V three-phase systems are typical for larger consumers in living areas (e. g. for the air-conditioning systems in an office building). NEMA recommends a rated motor voltage of 200 V for these systems.

	Rated voltage of the network	Rated voltage (operating voltage) of the motor	
	Nominal Power System Voltage	Motor Utilisation (Nameplate) Voltage	
		usual	old
USA	120 V (1 ph)	115 V (1 ph)	110 V (1 ph)
	208 V	200 V	190 V
	240 V	230 V	220 V
	480 V	460 V	440 V
Canada	600 V	575 V	550 V

Table 30.2 Voltage designation in North America – frequency 60 Hz in each case

Whilst North American users regard it as accepted practice to supply motors with "460 V" marked on the rating plate for installations with a mains designation of "480 V", this practice can cause problems for European equipment (OEM) suppliers if they are not sufficiently aware. If there is any doubt, it is recommended that clarification is sought beforehand or that the winding and labelling are designed exactly in accordance with the order. According to NEMA MG1-12.45 the voltage may deviate by ± 10 % from the rated voltage. The motor should work "successfully" at the limits of this (relatively large) voltage range, but it is not essential for its power figures to agree with the values specified for the rated voltage (comparable with Range B, in accordance with IEC 60034-1).

30.3 Terminal markings

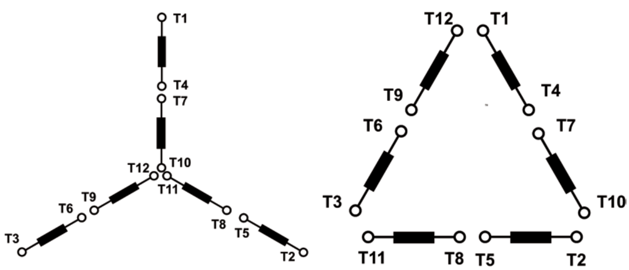


When exporting to North America, it is particularly important to mark the ends of the winding clearly. For small and medium-sized motors, the practice there is to run the ***ends of the winding*** into the terminal boxes as ***loose leads***, i.e. they are not run onto a terminal board. The electrician then usually crimps the ends of the winding onto the line conductors in accordance with mains voltage and winding connections. To be able to do this, the electrician must be able to identify each individual winding end, whilst his European colleague can insert the triangular or star connections "blind" (**Figure 30.3.1**). The American argument in favour of this method of connection is that when a motor is fitted to the floor and the terminal box is located on the side, it is easier to identify long ends of the winding when they can be pulled out of the box than it is to identify winding ends concealed in the terminal box or imprints on the terminal board! Danfoss Bauer motors do have fixed terminal board markings, however.

Figure 30.3.1 Typical North American motor terminal box: Loose winding ends (no terminal board) for "wire-to-wire" connection to the line conductors

Figure 30.3.2
Terminal markings for Y (YY) or Δ (ΔΔ) connection (with series or parallel connection)

Tap changing
(2 : 1, e. g. 460/230 V)



30.4 Pole changing

The Dahlander connection is known – if at all – as “tapped wound” or “two speed consequent pole connection” in North America. It is much less common than in Europe. It should therefore not be assumed that the supplier for a 1:2 pole-changing motor automatically has the Δ/YY Dahlander connection in mind. It is instead likely that he will supply a connection with two separate windings (e. g. Y/Y), i.e. a „dual wound“ motor, which is the solution commonly used in North America and is a more simple connection from a control engineering point of view. It is recommended that technical matters are clarified before delivery and that the term “Dahlander connection” is explained to users in N.A.!

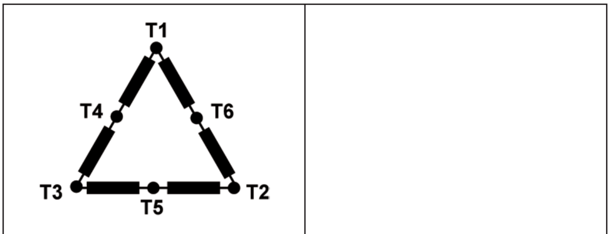


Figure 30.4.1
Terminal markings for D/YY pole-changing Dahlander connection = two speed consequent pole connection = tapped wound

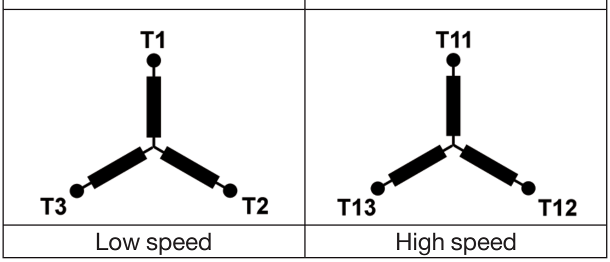


Figure 30.4.2
Terminal markings for pole-changing with two separate Y/Y windings = dual wound

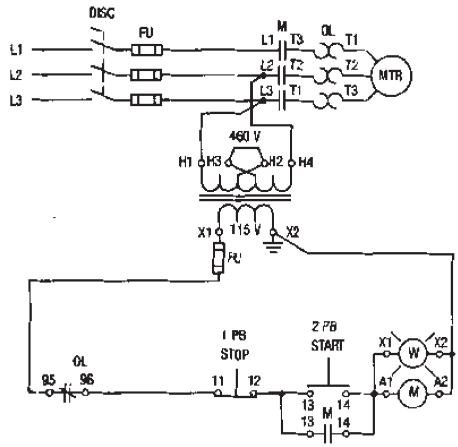
30.5 Starting process

The Y-Δ (star-delta) starting procedure often used in Europe to reduce starting current and breakaway torque is comparatively little used in North America. Knowledge of circuit engineering and availability of ready-to-use contactor controls cannot always be assumed. Part-winding starting is relatively common. This is defined in NEC 430-3. This requires a stator winding in which two groups are energised in parallel in normal operation. Parallel connection is not used for starting, i.e. only one of the two groups is live. This has the effect of a series resistor and reduces the breakaway torque and starting current, although not to the same degree as with Y-Δ starting. The starting current is reduced to around 70 % and breakaway torque to around 50 %.
Further information can be found in the Danfoss-Bauer book “Starting, braking, positioning with three-phase cage induction motors”.

30.6 Symbols for circuit diagrams

So far, the internationally standardised symbols (e. g. in IEC 60617) have not been adopted in North America. Electricians in North America will only be able to read circuit diagrams if they have been drawn up in “their language”.

Figure 30.6
Example of a circuit diagram for a direct motor starter with fused interrupter and motor protection relay showing the standard symbols in use in North America (according to documents from MOELLER)



The switchgear manufacturers provide comprehensive documentation on this matter and produce switch cabinets and circuit diagrams in accordance with North American standards. It is worth noting that adaptation to North American standards does not just require the circuit diagram to be changed. Equipment regulations also require a ***different component layout***, e. g. for the contactors.

30.7 Type of construction and mounting arrangement

The abbreviations for the main types of mountings are listed in the following comparison. The abbreviations for types of installation such as “flange”, “pedestal bearing” etc., are not provided for in the NEMA system – by contrast, the position of the terminal box is given its own abbreviation. It is particularly worth noting that on conventional foot-mounted motors (F-1) the terminal box is located ***on the left*** when looking towards the front face of the shaft. Positioning the terminal box on the right, as is conventional practice in Europe, is regarded as a special design (F-2).

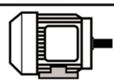
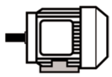
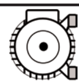
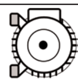
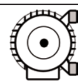
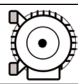
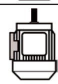
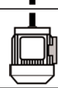
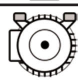
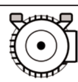
Type of mounting	Symbol	NEMA	IEC 60034-7	Terminal box
Floor		**F-1**	IM B3 IM 1001	Left
		**F-2**	IM B3 IM 1001	Right
Wall		**W-1**	IM B7 IM 1061	Right
		**W-2**	IM B6 IM 1051	Left
		**W-3**	IM B7 IM 1061	Left
		**W-4**	IM B6 IM 1051	Right
		**W-5**	IM V6 IM 1031	Right
		**W-6**	IM V5 IM 1011	Left
		**W-7**	IM V5 IM 1011	Right
		**W-8**	IM V6 IM 1031	Left
Ceiling		**C-1**	IM B8 IM 1071	Right
		**C-2**	IM B8 IM 1071	Left

Table 30.7 Mounting arrangement according to NEMA MG1-4.3, compared with IEC 60034-7

30.8 Frame size

The following table lists comparable IEC/EN and NEMA frame sizes and associated shaft diameters.

IEC 60072-1/EN 50347		NEMA MG1-4.4		
Frame size	Shaft Ø mm	Frame Size	Shaft Ø inch	mm
90S	24	143T	0.875	22.2
90L	24	145T	0.875	22.2
100L	28	–	–	–
112M	28	184T	1.125	28.6
132S	38	213T	1.375	34.9
132M	38	215T	1.375	34.9
160M	42	254T	1.625	41.3
160L	42	256T	1.625	41.3
180M	48	284T	1.875	47.6
180L	48	286T	1.875	47.6
200L	55	326T	2.125	54
225S	60	364T	2.375	60.3
225M	60	365T	2.375	60.3
250M	65	405T	2.875	73
280S	75	444T	3.375	85.7
280M	75	445T	3.375	85.7

Table 30.8 Comparable IEC/EN and NEMA frame sizes and shaft diameters of for 4-pole three-phase induction motors

30.9 Apparent locked rotor power (Code Letter)

The mains network conditions in North America make it necessary to examine the additional loading (“inrush”) which occurs during switch-on. NEMA MG1-10.37 calls for the ***apparent locked rotor power*** P_A (kVA) to be related to the output (HP), i.e. the ratio P_A/P_N given as kVA/HP whereas the starting current ratio I_A/I_N is used as the characteristic value in Europe.
This characteristic value is specified as a “Code Letter” in accordance with the following table:

Code Letter	kVA/HP	**Code Letter**	kVA/HP
A	< 3.15	**K**	≥ 8.0 ... < 9.0
B	≥ 3.15 ... < 3.55	**L**	≥ 9.0 ... < 10
C	≥ 3.55 ... < 4.0	**M**	≥ 10 ... < 11.2
D	≥ 4.0 ... < 4.5	**N**	≥ 11.2 ... < 12.5
E	≥ 4.5 ... < 5.0	**P**	≥ 12.5 ... < 14
F	≥ 5.0 ... < 5.6	**R**	≥ 14 ... < 16
G	≥ 5.6 ... < 6.3	**S**	≥ 16 ... < 18
H	≥ 6.3 ... < 7.1	**T**	≥ 18 ... < 20
J	≥ 7.1 ... < 8.0	**U**	≥ 20 ... < 22.4
		V	≥ 22.4

Table 30.9.1 Code letters in accordance with NEMA MG1-10.37

The following applies to special designs:

- ☐ Pole-changing: Highest code letter
- ☐ Voltage switching: Highest code letter if they differ
- ☐ 50/60 Hz frequency: Code letter for 60 Hz
- ☐ Star-delta (Y-Δ) starting: Code letter for star starting step
- ☐ Part winding starting: Code letter for direct-on-line starting on full winding

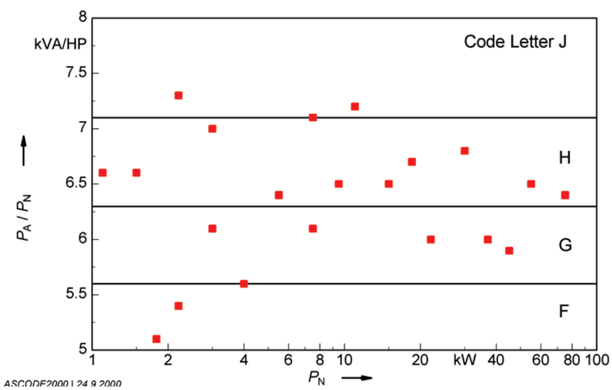
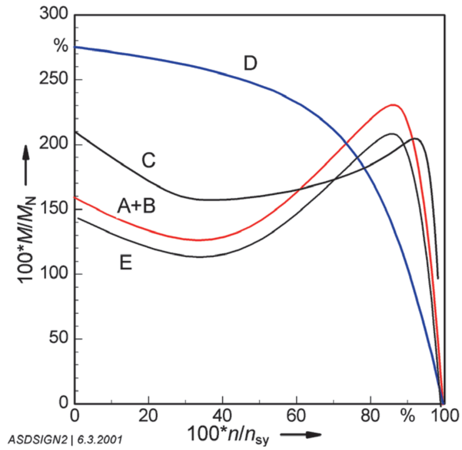


Figure 30.9.1
Scatter band of Code Letters for 4-pole catalogue motors from Danfoss Bauer GmbH

30.10 Torque-speed characteristics

NEMA offers a choice of five variants which differ in their basic torque/speed pattern and in their relative starting current. These designs are denoted ***"A, B, C, D, E"***. Design A has the same torque characteristics as B but with a higher starting current.

Figure 30.10
Basic torque-speed characteristics of NEMA designs A, B, C, D, E
(in accordance with NEMA MG10)



The breakaway torque, pull-out torque and starting current limits are tabulated in NEMA MG1. ***Design B is mostly used*** for conventional applications, although the standard limits slip to 5 %, regardless of frame size (NEMA MG1-1.18.1.2). This seems technically unnecessary and barely achievable for small machines.
Design D (soft characteristics without any definite breakdown torque) is preferred for applications requiring a high peak torque (presses, shears, lifting gear).
Design E denotes a motor with a particularly high efficiency (higher than is legally specified in "EPCA", cf. Danfoss-Bauer special publication SD 34..) – a variant that has not yet gained general acceptance.

30.11 Cable entry to the terminal box

In contrast to Europe, where 4-core cable is usually laid, the main preference in North America is for the ***Conduit System***: The cables are routed in rigid pipes or flexible hoses of metal of plastic, which are connected or inserted into each other by means of special threads (***NPT*** = National Taper Pipe Thread). The cable laying technique is reminiscent of installing gas or water pipes. Individual wires are laid in the pipes. Whilst the European electrical systems installer expects ***three*** metric (formerly Pg) entry threads (for 3(4)-core cables) on a pole-changing motor with three speeds (9 terminals), the best that his North American colleague gets is ***one*** entry thread which is as large as possible.

NPT	ID	Inside Ø	OD	Outside Ø	I_{max} in accordance with CSA
inch	inch	mm	inch	mm	A
1/2	0.622	15.8	0.840	21.3	16
3/4	0.824	20.9	1.050	26.7	32
1	1.049	26.6	1.315	33.4	44
1 1/4	1.380	35.1	1.660	42.2	80
1 1/2	1.610	40.9	1.900	48.3	88
2	2.067	52.5	2.375	60.3	130
2 1/2	2.469	62.7	2.875	73.0	190
3	3.068	77.9	3.500	88.9	250
3 1/2	3.548	90.1	4.000	101.6	320
4	4.026	102.3	4.500	114.3	360

Table 30.11.1 Inside (ID) and outside (OD) diameters of conduit with NPT threads

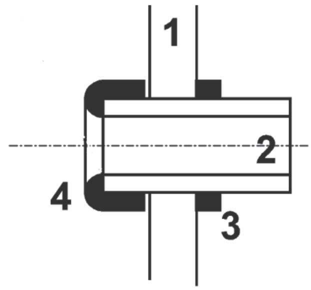
The thread is conical to establish as good a contact as possible between the pipe and the terminal box (motor frame), because a ground connection via the pipe is permitted. This method of grounding is not undisputed in North America either, because the “tightening torques” are inadequately defined and there is a risk of corrosion; however, as before, it is permitted in the NEC.

FRAME	14X	18X	21X	25X	28X	32X	36X	40X	44X
NPT	¾	¾	1	1 ¼	1 ½	2	3	3	3

Table 30.11.2 Minimum NPT entry thread size for NEMA-T-Frames, in accordance with NEMA MG1-4.4.1

The pipe protrudes into the terminal box; because of the sharp edges, the installer must protect it on the inside in the form of a protective nut ("bushing"), whilst on the outside it must be locked with a ring nut. This is one of the reasons why ***substantial clearances*** are required in the terminal box.

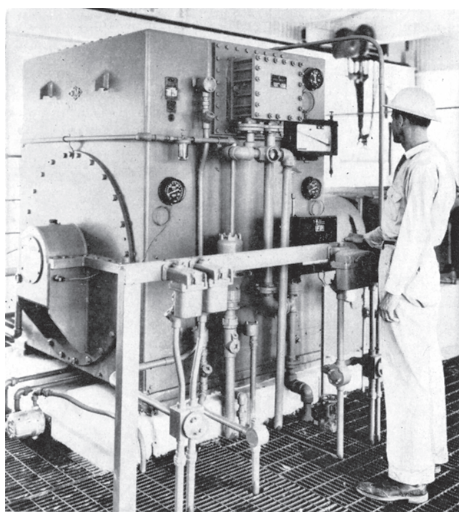
Figure 30.11.3
Example of a conduit entry in a terminal box
1 – Wall of the terminal box
2 – Pipe (conduit) for entry of line conductor
3 – Ring nut for locking
4 – Nut for protecting against sharp edges



The following NPT / Pg conduit thread and NPT / metric reducer nipples are available for example from R. Stahl Schaltgeräte GmbH.

NPT	3/8	1/2	1/2	1/2	3/4	3/4	1	1 1/4	1 1/2	2
Pg	7	9	11	13,5	13,5	16	21	29	36	48
M	10	10	-	-	16	-	20/25	32	32	50

Figure 30.11.4
Example of an electric installation using the conduit system
Source: Worthington Corp.



30.12 Frequently used abbreviations

Abb.	Meaning	Bedeutung deutsch
A	Ampere	Ampere
AC	Alternating current	Wechselstrom
AFD	Adjustable frequency drive	Frequenzumrichter(antrieb)
AMB	Ambient	Umgebung(stemperatur)
AMPS	Ampere	Ampere, Stromstärke
ARM	Armature	Anker
ASD	Adjustable speed drive	Drehzahlverstellbarer Antrieb
ASM	Asynchronous machine	Asynchronmaschine
AVI	Adjustable voltage inverter	Umrichter mit var. U-Zwischenkreis
AWG	American wire gauge	Amerikanische Drahtlehre
BB	Ball bearing	Kugellager
BRG	Bearing	(Wälz)Lager
C	Celsius, Centigrade	°C, Celsiusgrad
C-#	Ceiling mounted	Decken-Anbau
C/S	Cycles per second	Zyklen pro Sekunde, Hz
CAP	Capacitor	Kondensator
CCW	Counterclockwise	Drehrichtung gegen Uhrzeigersinn
CFM	Cubic feet per minute	Kubik-Fuß pro Minute (1 cfm = 28,32 l/min)
CFM	Converter fed machine	Umrichtergespeiste Maschine
CL	Class of insulation	Isolierstoffklasse (Wärmeklasse)
CODE	Code letter	Kennbuchstabe für Blockier-kVA/HP
COMM	Commutating	Kommutierung
COMP	Compensating	Kompensation
CON	Contactor	Schaltschütz
CONN	Connection	Connection
CONT	Continuous	Dauernd, Dauerbetrieb S1
CPD	Compound	Kompound
CSI	Current source inverter	Umrichter mit Strom-Zwischenkreis
CW	Clockwise	Drehrichtung im Uhrzeigersinn
DC	Direct current	Gleichstrom
DE	Drive end	Antriebsseite
DESIGN #	NEMA Design #	Kennbuchstabe für Drehmoment-Charakteristik
DIAG	Diagram	Diagramm, Schaltbild
DIP	Dust-ignition-proof	Staubexplosionsgeschützt
DP	Drip-proof	Tropfwassergeschützt
DR. END	Drive end	Antriebsseite
DSG	Design	Klassifizierung der Drehmoment-Charakteristik
EEM	Energy efficient motor	Energiesparender Elektromotor
EFF	Efficiency	Wirkungsgrad
ENCL	Enclosure	Gehäuse (Schutzart)
ETD	Embedded temp. detector	Eingebetteter Temperaturwächter
EVSD	Electric variable speed drive	Elektrisch drehzahlverstellbarer Antrieb
EXC	Excitation	Erregung
F	Fahrenheit	Fahrenheit

30.12 Frequently used abbreviations

F-#	Floor mounted	Boden-Aufstellung
FF	Form factor	Formfaktor
FHP	Fractional horsepower	Kleinmotor, Leistung < 1 HP
FLA	Full load amperes	Bemessungsstrom, Volllaststrom
FLD	Field	Feld
FR	Frame	Baugröße
FREQ	Frequency	Frequenz
FV	Open externally-ventilated	Offen, mit Rohranschluss am Lufteintritt, fremdbelüftet
FW	Field weakening	Feldschwächung
GEN	Generator	Generator
GP	General purpose	Offene Maschine für allgemeine Verwendung
GPM	Gallons per minute	Gallonen pro Minute (1 US gal = 3,785 l)
GPS	Gallons per second	Gallonen pro Sekunde (1 US gal = 3,785 l)
GRD	Ground	Erde
H	Henry	Henry
HI	High	Hoch, obere Grenze
HP	Horsepower	Pferdestärke (1 HP = 0,746 kW)
HR	Hour	Stunde
HTR	Heater	Heizelement
HZ	Hertz	Hertz
IND	Induction	Induktion
INS	Insulation (system class)	Isolierstoffklasse, Wärmeklasse
INST	Instrument	(Anzeige) Instrument
INT	Intermittent duty	Aussetzbetrieb
IOL	Instantaneous overload	Plötzliche Überlastung
KVA	Kilovolt-ampere	kVA
KVAR	Reactive kilovolt-ampere	kVar
KW	Kilowatt	kW
L1 (2, 3)	Line 1 (2, 3)	Außenleiter 1 (2, 3)
LB-FT	Pound-feet	Drehmoment-Einheit (1 lb-ft = 1,356 Nm)
LO	Low	Tief, untere Grenze
LRA	Locked rotor amperes	Anzugsstrom
LS	Limit switch	Grenzschalter
MAX	Maximum	Maximum, maximal
MB	Magnetic brake	Magnetbremse
MC	Magnetic clutch	Magnetkupplung
MCS	Motor circuit switch	Motorschütz
MFD	Microfarad	Mikrofarad
MG	Motor-generator	Motor-Generator (satz)
MH	Millihenry	Millihenry
MHP	Millihorsepower	Millihosepower (1 mHP = 0,746 W)
MIN	Minimum	Minimum, minimal
MIN	Minutes	Minuten
MOUNT	Mounting	Anbau, Aufstellung
MTR	Motor	Motor
NDE	Non-drive ind	Gegen-Antriebsseite
NEMA	NEMA	Normenorganisation in den USA

NPT	National taper pipe thread	Einführungsgewinde
ODDP	Outdoor drip-proof	Offen, tropfwassergeschützt, Aufstellung im Freien
ODP	Open drip-proof	Offen, tropfwassergeschützt
OL	Overload relay	Überlast-Relais
OPP DE	Opposite drive end	Gegen-Antriebsseite
OZ-FT	Ounce-feet	Drehmoment-Einheit (1 oz-ft = 8,47 cNm)
OZ-IN	Ounce-inch	Drehmoment-Einheit (1 oz-in = 0,706 cNm)
PB	Push button	Drucktaster
PER	Periodic duty	Perodischer Betrieb
PF	Power factor	Leistungsfaktor
PH	Phase(s), Number of phases	Phase(n), Phasenzahl
POT	Potentiometer	Potentiometer
PV	Open pipe-ventilated	Offen, mit Rohranschluss am Lufteintritt, eigenbelüftet
PWM	Pulse width modulation	Pulsbreitenmodulation
QVR	Varistor	Varistor
RB	Roller bearing	Rollenlager
RECT	Rectifier	Gleichrichter
RES	Resistance	Widerstand
RHEO	Rheostat	Einstellbarer Messwiderstand
RMS	Root mean square	Quadratischer Mittelwert
ROT	Rotation	Drehung
RPM	Revolutions per minute	Drehzahl, Umdrehungen pro Minute
RTD	Resistance temp. detector	Widerstandsthermometer
SB	Sleeve bearing	Gleitlager
SCR	Silicon controlled rectifier	Thyristor
SEC	Second (time)	Sekunde
SEC	Secondary	Sekundär
SER	Serial (number)	Seriennummer
SER	Series	Serie
SF	Service factor	Betriebsfaktor
SFA	Service factor amperes	Strom bei Ausnutzung des Betriebsfaktors
SH	Shunt	Nebenschluss
SHP	Shaft horsepower	(Mechanische) Leistung an der Welle
SHTD	Short-time duty	Kurzzeitbetrieb
SOL	Solenoid	Magnetspule
SP	Splash-proof	Spritzwassergeschützt
SPL	Special	Spezial
SR	Synchronous reluctance	Reluktanz-Synchronmotor
STAB	Stabilized, stabilizing	Stabilisierung
STD	Standard	Norm, genormt
T	Transformer	Transformator
T#	Terminal marking	Anschlussbezeichnung
T/C	Thermocouple	Thermoelement
TACH	Tachometer	Drehzahlgeber
TB	Terminal block	Klemmenleiste
TC	Thermocouple	Thermoelement
TE	Totally-enclosed	Völlig geschlossen

TEFC	Totally-enclosed fan-cooled	Völlig geschlossen, oberflächenbelüftet
TEFP	Totally-enclosed flameproof	Völlig geschlossen, druckfest gekapselt
TEFV	Totally-enclosed forced-ventilated	Völlig geschlossen, fremdbelüftet
TEMP RISE	Temperature rise	Temperaturerhöhung, Erwärmung
TENV	Totally-enclosed nonventilated	Völlig geschlossen, unbelüftet
TEPV	Totally-enclosed pipe-ventilated	Völlig geschlossen, mit Rohranschluss für Durchzugbelüftung
TERM	Terminal	Klemme
TEWA	Totally-enclosed water-air-cooled	Völlig geschlossen, Luft/Wasser-Wärmetauscher
TEWC	Totally-enclosed water-cooled	Völlig geschlossen, Leiter direkt wassergekühlt
TH	Thermometer	Thermometer
TIME	Time rating	Auslegung für begrenzte Laufzeit
TORQ	Torque	Drehmoment
TR	Time delay relay	Zeitrelais
TYPE	Type	Typ
TYPE #	NEMA 250 type of enclosure	Gehäuse-Schutzart nach NEMA 250
V	Volts, Voltage	(Bemessungs)spannung in V
VA	Volt-amperes	VA
VAR	Varying duty	Betrieb mit Wechselbelastung
VAR	Reaktive volt-amperes	Var
VF	Variable frequency	Verstellbare Frequenz
VFD	Variable frequency drive	Frequenzumrichter(antrieb)
VM	Voltmeter	Spannungsmesser
VOLTS	Volts	(Bemessungs)spannung in V
VSD	Variable speed drive	Antrieb mit verstellbarer Drehzahl
VSI	Voltage source inverter	Umrichter mit Spannungs-Zwischenkreis
VVI	Variable voltage input	Einstellbare Eingangsspannung
W	Watt	Watt
W-#	Wall mounted	Wand-Aufstellung
WDG	Winding	Wicklung
WM	Wattmeter	Leistungsmesser
WP	Weather-protected	Offene, durchzugbelüftet, mit Wetterschutz
WPRF	Water-proof	Völlig geschlossen, strahlwassergeschützt
WRIM	Wound rotor induction motor	Schleifringläufer-Motor
WT	Weight	Gewicht (Masse)
XP	Explosion-proof	Explosionsgeschützt

VI EMISSIONS

31 Noise

Noise level limits going back to drafts devised in 1962 were included early on in the 1966 issue of VDE 0530 “Regulations for electrical machines”. This publication documented the early efforts of manufacturers and users of electrical machines, as well as the German standards committees, to make an active contribution to ***environmental protection*** – efforts that were made without any prompting from authorities and without widespread public environmental awareness.
Detailed information on this subject can be found in the Danfoss-Bauer special publication SD 1800.

31.1 Limits for all types of machines

As an “umbrella” guide, to a certain extent, for ***all types*** of rotating electrical machines, table 1 of the standard specifies limits for six speed stages in the 600 ... 3750 r/min range, for ten IC cooling methods (in accordance with IEC 60034-6) and for four typical IP degrees of protection (in accordance with IEC 60034-5). The extract in **Table 31.1** is limited to the range covered by frame sizes comparable with standard motors. The first power group ($1.0 < P_N \leq 1.1$) is not that meaningful but has been designated as correct by the competent authority.

n_N in r/min ➔		$n_N \leq 960$	$960 < n_N \leq 1320$	$1320 < n_N \leq 1900$	$1900 < n_N \leq 2360$	$2360 < n_N \leq 3150$	$3150 < n_N \leq 3750$
➔ P_N in kW	L_S* in dB 1) / 2)	No-load limit for the A-weighted sound power level L_{WA} in dB(A)					
$1.0 < P_N \leq 1.1$	9 / 12	73	76	78	81	84	88
$1.1 < P_N \leq 2.2$	10 / 12	74	78	82	85	88	91
$2.2 < P_N \leq 5.5$	10 / 12	78	82	86	90	93	95
$5.5 < P_N \leq 11$	10 / 12	82	85	90	93	97	98
$11 < P_N \leq 22$	11 / 13	86	88	94	97	100	100
$22 < P_N \leq 37$	11 / 13	90	91	98	100	102	102
$37 < P_N \leq 55$	11 / 14	93	94	100	102	104	104
$55 < P_N \leq 110$	12 / 14	96	98	103	104	106	106
$110 < P_N \leq 220$	12 / 14	99	102	106	107	109	110
$220 < P_N \leq 550$	12 / 15	102	105	108	109	111	113

* Guide value not contained in the standard for $1320 < n_N \leq 1900$ rpm (e. g. 4-pole 3-phase induction motor)
1) In accordance with DIN 45635, Part. 1/05.74 (outdated) 2) In accordance with DIN EN 21680/11.91

Table 31.1 Noise limits in accordance with IEC 60034-9 (1997) for electrical machines of all types in the standardised frame size range; cooling method IC 411, degree of protection IP44 or IP54

31.2 Limits for three-phase cage motors (standard motors)

A principle which has been tried and tested in German standards practice for some time has, for the first time, been adopted into IEC 60034-9: The noise limits for the most commonly used and advanced (in terms of development) standard motors are listed separately in Table 2 in the standard. When using this and the following tables, it should be noted that the noise limits are graded in accordance with rated motor outputs. They can also be related to a motor frame size by means of the unit rating, if the frame size is fully utilised within the scope of the standards.

n_N in r/min →		8-pole 50 Hz	8-pole 60 Hz	6-pole 50 Hz	6-pole 60 Hz	4-pole 50 Hz	4-pole 60 Hz	2-pole 50 Hz	2-pole 60 Hz
↓ P_N in kW	L_S * in dB 1) / 2)	**No-load limit for the A-weighted sound power level L_{WA} in dB(A)**							
1.0 < P_N ≤ 2.2	10 / 12	71	71	71	71	71	71	81	85
2.2 < P_N ≤ 5.5	10 / 12	76	76	76	76	76	76	86	88
5.5 < P_N ≤ 11	10 / 12	80	80	80	80	81	81	91	91
11 < P_N ≤ 22	11 / 13	84	84	84	84	88	88	94	94
22 < P_N ≤ 37	11 / 13	87	87	87	87	91	91	96	100
37 < P_N ≤ 55	11 / 14	89	90	90	91	94	95	98	101
55 < P_N ≤ 110	12 / 14	92	93	94	95	97	98	100	104
110 < P_N ≤ 220	12 / 14	96	97	98	99	101	102	103	107
220 < P_N ≤ 550	12 / 15	98	99	101	102	105	106	107	110

* Guide value for 4-pole standard motor
1) In accordance with DIN 45635, Part. 1/05.74 (outdated) 2) In accordance with DIN EN 21680/11.91

Table 31.2 A-weighted sound power limits for three-phase standard motors in accordance with IEC 60034-9 (1997), Table 2

31.3 Emissions characteristics of standard motors (ETS)

Noise emissions characteristics for machines of all types are collated and shown in comparable form by the joint committee on the “Emissions characteristics of technical noise sources” (ETS) of the Normenausschuss Akustik und Schwingungstechnik (DIN - FANAK) (Acoustics and Vibration Engineering Standardisation Committee) of the Deutsches Institut für Normung e.V. (DIN) (German Standards Institute) and by the CDI-Kommission Lärmminderung (VDI-KLM) (VDI Committee on Noise Reduction) of the Vereins Deutscher Ingenieure (VDI) (Association of German Engineers). The results for rotating electrical machines are contained in the VDI code of practice VDI 3736 Sheet 1, April 1984. The survey figures do not therefore reflect the absolute “state-of-the-art”, but do form the only document of this quality that is available.

In the interim period, the manufacturers of standard motors have made considerable efforts to reduce, in particular, the fan noise on larger machines. The success achieved can be seen in **Figure 31.3** which shows the mean values (marked CAT-99) of catalogue data from four German manufacturers. It is noticeable that the data from the various manufacturers lie close together on the graph – an indication that a high level of technological maturity has been reached. The scatter band labelled DB-GM represents the noise levels of Danfoss-Bauer geared motors which have been calculated under comparable measurement conditions. The noise reductions on the "motor" component, which can be achieved using relatively simple means, are not sufficient to reduce the ***overall noise of the "geared motor" unit*** significantly.

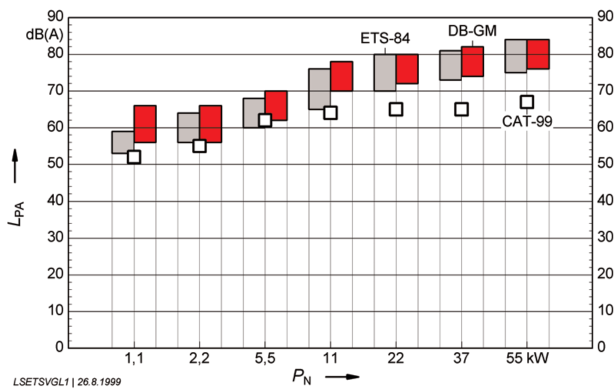


Figure 31.3
Comparison of emissions from technical noise sources (ETS); measured in each case as the sound pressure level at rated output, at a distance of 1 m

ETS-84
VDI code of practice 3736 Sheet 1, April 1984
DB-GM
Scatter band of Danfoss-Bauer geared motors, series 2000
CAT-99 Catalogue data of four manufacturers of standard motors (without gear units)

31.4 Emissions characteristics of gear units (ETS)

The noise emission characteristics for gear units were measured between 1977 and 1981 by the Laboratorium fur Werkzeugmaschinen und Betriebslehre (Laboratory for Machine Tools and Industrial Management) of the RWTH Aachen as part of a research project of the Forschungsvereinigung Antriebstechnik e. V. (Drive Technology Research Institute). The emissions graphs are shown in code of practice VDI 2159, July 1985; they are based on noise tests carried out on 149 gear units from a total of 37 manufacturers. The measurement results are statistically analysed and shown in the code of practice as a wide scatter band. An 80 % line was selected as an estimate of the results of standard measurements. This percentage line was calculated using a non-parametric statistical estimation method. The 80 % line, which is also expressed by the logarithmic equation in the type-specific diagrams, states that 80 % of the noise emission values for the type of gear unit in question, which are calculated in accordance with DIN 45635 Part 23 or the special measurement procedures described in the Appendix, are below this graph.

This statement is correct with a probability of 90 % and applies to the technical conditions prevailing at the time of the tests (1985). According to the compiler of the final report of this comprehensive series of tests, which has so far not been repeated in this form, the current level of technical development and the high level of production quality can be expected to bring about a further reduction in noise levels of around 5 dB. This has also been taken into account in the comparison.
Figure 31.4.1 shows a comparison of the scatter band of the rated noise levels for Danfoss-Bauer helical gear units (without motor) with the 80 % lines of the ETS (published based on 1985 conditions and converted to 1999 conditions).
Figure 31.4.2 is the same comparison, but for bevel-gear units.

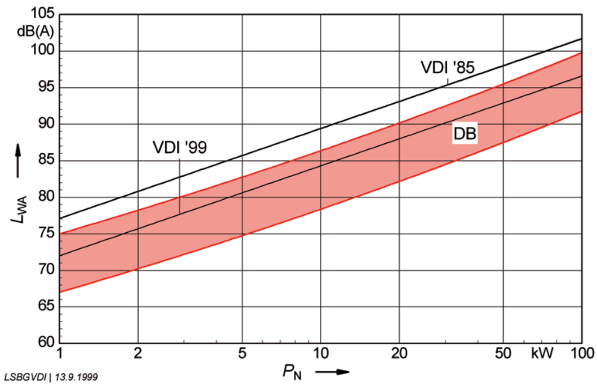


Figure 31.4.1
Comparison of sound power levels L_{WA} for helical-gear units with rated outputs of P_N = 1 ... 100 kW

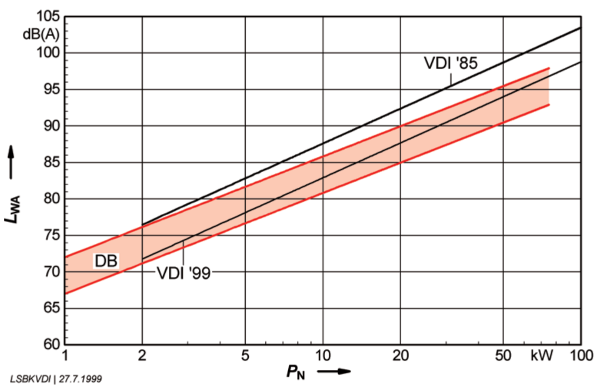


Figure 31.4.2
Comparison of sound power levels L_{WA} for bevel-gear units with rated outputs of P_N = 1 ... 100 kW

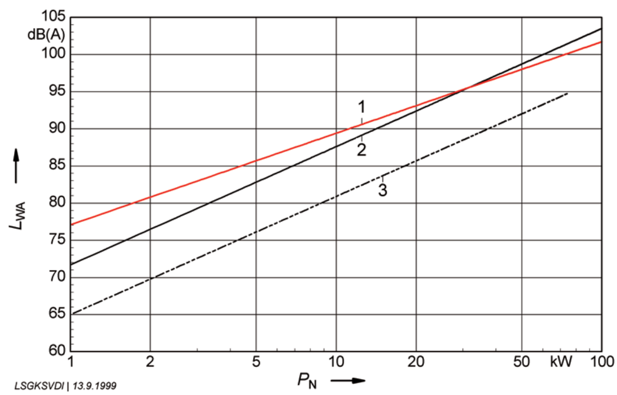
See page 31-5 for a key to the abbreviations.

VDI '85 80 % line in accordance with ETS VDI code of practice 2159, valid for 80 % of all gear units manufactured (without motor); 1985 conditions
VDI '99 80 % line in accordance with ETS VDI code of practice (without motor), converted to 1999 conditions
DB Scatter band of rated values (with motor) for Danfoss-Bauer gear units

This fundamental study also enabled a ***comparison of different types of gear units*** based on the same measurement conditions. The 1985 80 % lines for helical-gear units, bevel-gear units or bevel-helical-gear units and worm-gear units without helical-gear stage are compared (**Figure 31.4.3**). The current status is around 5 dB lower, at least for the helical-gear and bevel-gear units. It can also be noted that most modular worm-gear units in geared motors have an upstream helical-gear stage, which is significant for the overall noise level. The substantial noise advantage offered by the worm-gear unit, as shown in the diagram, only applies if there is ***no helical-gear stage*** upstream.

Figure 31.4.3
Comparison of noise emissions

1 Helical-gear units
2 Bevel-gear units and bevel-helical-gear units
3 Worm-gear units (without helical-gear stage)



31.5 Guide values for the noise levels of geared motors

The scatter band shown in **Figure 31.5** of guide values for the A-weighted sound pressure levels of 4-pole three-phase helical-geared motors takes into account both the effects of gear unit size and reduction ratio as well as the degree of load and tolerances. The limit line in accordance with DIN VDE 0530 Part 9, Table 1, applies for all types of rotating electrical machines. Table 2 of this standard specifies lower limits for standard motors. It is worth noting, and can be regarded as evidence of the high level of development and production quality of Danfoss-Bauer drives, that the noise limit guide values for geared motors are in part substantially below the limits that were specified for electric motors ***without gear units***.
The current level of development for helical-gear reduction gearing (without motors), has also been plotted in the diagram for the power range of 0.7 to 100 kW, in accordance with VDI 2159 Emissions Characteristics of Technical Noise Sources.

According to this, the entire scatter band for 4-pole Danfoss-Bauer geared motors is substantially below the noise emissions values which, according to the VDI code of practice, can be expected for 80 % of all helical-gear units (without motors).

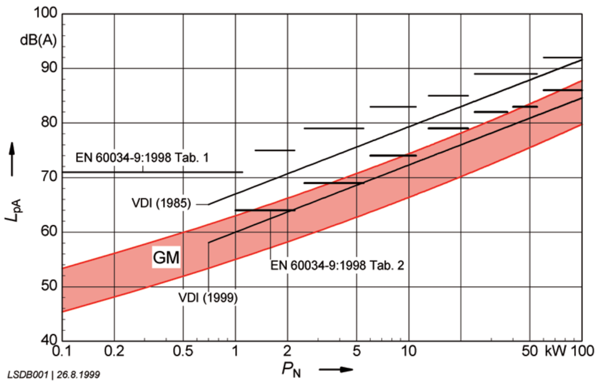


Figure 31.5
Guide values for the A-weighted sound pressure levels L_{pA} of 4-pole three-phase helical-geared motors, measured from a distance of 1 m (GM) at rated outputs of 0.1 ... 100 kW and compared with the following stipulations

EN 60034-9:1998 Tab. 1 Applies to all types of electrical machines rotating at speeds of around 1500 r/min, converted from power level to pressure level and with the additional load as stipulated in Table 3 of the standard
EN 60034-9:1998 Tab. 2 Applies to 4-pole 50 Hz three-phase cage motors, IP44 ...IP55, IC411; with maximum additional load for full load as per Table 3, identical with IEC 60034-9:1997, Tables 2 and 3
VDI (1985) Code of Practice VDI 2159, applies to 80 % of all industrial helical-gear units (without motors), 1985 conditions
VDI (1999) Code of Practice VDI 2159, applies to 80 % of all industrial helical-gear units (without motors), 1999 conditions
GM Scatter band of Danfoss-Bauer geared motors, series 2000

Figure 31.5 shows the A-weighted sound ***pressure*** level, because this is still the preferred parameter in practice. The noise ***power*** level mentioned in the standard is around 12 ... 14 dB higher, depending on the frame size of the drive unit, if it has been determined in accordance with EN 21680/11.9. Compared with earlier stipulations in DIN 45635 Part 1 there are differences of around 2 ... 3 dB.
The number of possible different types or frame sizes is considerably higher for geared motors than for standard motors; even within one specific type combination there may be substantial design differences in addition to those differences resulting from production and measurement error tolerances. If, therefore, a relatively low noise level is to be stipulated as mandatory at the project stage, it is recommended in each case that the manufacturer is contacted in good time.

32 Vibrations

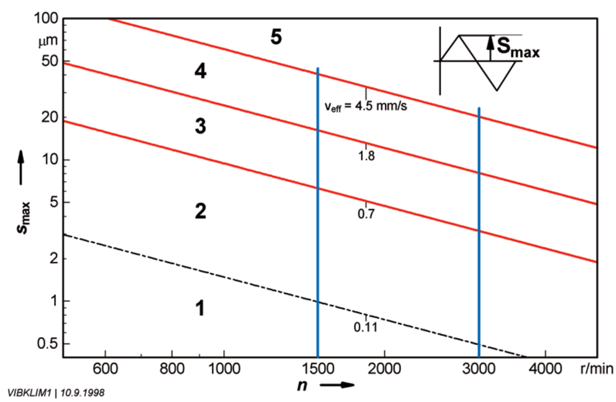
Mechanical vibration cannot be entirely eliminated. If permissible limit values are exceeded, vibration can lead to malfunctions with considerable consequential damage.
VDI Code of Practice 2056 is recognised internationally and adopts ***vibration severity*** as the measurement of vibration levels. This corresponds to the effective value of the ***speed of vibration***. The Code of Practice deals primarily with the emission (output) of vibrations. As there are no universally-recognised standards or codes of practice specific to electrical machines for permissible levels of ***immission*** (action), VDI Code of Practice 2056 can also be used as a guide for the permissible vibrational stress.
Machines are categorised into groups K, M, G, T, D, and S. Of these, the following are of most significance for electrical machinery:

- ☐ Group K: of particular significance for mass-produced electric motors up to approximately 15 kW,
- ☐ Group M: of particular significance for electric motors with a power rating of 15 to 75 kW.

The rating limits for these machine groups are shown in two diagrams as a simplified extract of the whole in **Figure 32.1**. Here:

s_{max} Displacement (half-wave peak value)
n Speed of rotation
v_{eff} Effective speed of vibration (velocity)
1 Range below the average threshold of human perception
2 "Good" range
3 "Acceptable" range
4 "Permissible" range
5 "Impermissible" range.

Figure 32.1
Rating limits for the vibration levels in accordance with VDI 2056
a) Machine group K



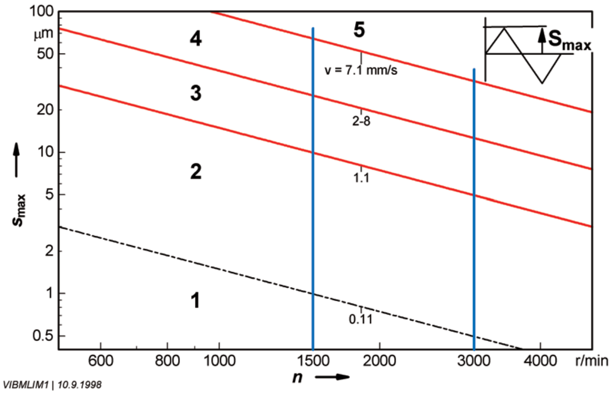


Figure 32.1
b) Machine group M

Vibration severity can be measured on-site by relatively simple means. Measuring conditions and measuring points are specified in VDI 2056 and ISO 2373.
Figure 32.2 provides a correlation between subjective perception and objective measured values and the rating limits:

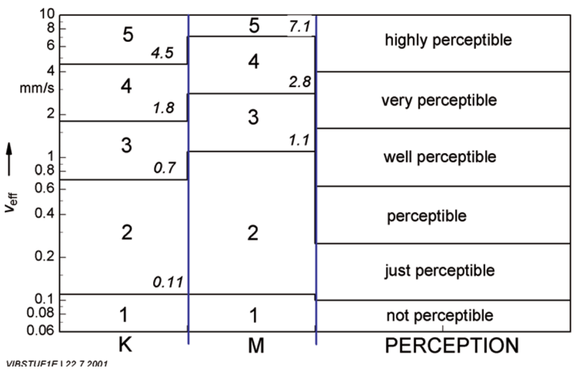


Figure 32.2
Correlation between subjective perception and the rating limits in accordance with VDI 2057

The FV1 safety data sheet issued by ZVEI, the German electrical and electronic manufacturers' association, designates the following limits for the action of external vibrations in the vicinity of bearings as harmless:

- ☐ Machine group K: $v_{eff} \leq$ 3.5 mm/s when running,
- ☐ Machine group M: $v_{eff} \leq$ 4.5 mm/s when running,
- ☐ All machine groups: $v_{eff} <$ 0.2 mm/s at rest (e. g. storage).

These operating values lie roughly in the middle of the "permissible" range shown.

DIN EN 60034-14 stipulates normal and special requirements for the ***balance quality*** of electrical machines. The mechanical vibrations of rotating electrical machines are measured in accordance with this standard and three ***levels of vibration severity*** are assigned. **Table 32.2** shows the limit values for the effective value of the speed of vibration veff as a function of the shaft height *H*.

Level	n_1 (r/min)	v_{eff} in mm/s für $80 \leq H \leq 132$	$132 < H \leq 225$	$225 < H \leq 400$
N (normal)	600 ... 3600	1.8	2.8	4.5
R (reduced)	600 ... 1800 > 1800 ... 3600	0.71 1.12	1.12 1.8	1.8 2.8
S (special)	600 ... 1800 > 1800 ... 3600	0.45 0.71	0.71 1.12	1.12 1.8

Table 32.2 Speed of vibration of electrical machinery in accordance with DIN EN 60034-14

With sinusoidal vibrations, the speed of vibration (velocity) *v* can be converted with the aid of angular frequency ω into an acceleration a which is then often given as a multiple of acceleration due to gravity *g*:

$$a = \omega \cdot v$$

33 Half-key balancing

This section explains the background to the new standard, compares the new regulations which were widespread in the past but are now mandatory for all manufacturers, and provides information on the correct assembly of ***"fitting elements"*** (couplings, belt pulleys, flywheels) on the shafts of standard motors.

33.1 Standard key conventions

The balancing method must be agreed where shafts and rotors with keys (for example on rotating electrical machines) and the fitting elements to be fitted onto them are manufactured separately and only assembled at the installation location. The following conventions are currently recognised:

- ☐ Full-key convention ("full-key balancing")
- ☐ Half-key convention ("half-key balancing")
- ☐ No-key convention ("balancing without a key").

The following methods are used world-wide in accordance with ISO 8821.

Country	Organisation	Key convention used
Australia	SAA	Not known
Austria	ON	Not known
Belgium	IBN	Not known
Canada	SCC	Half-key
Czechoslovakia	CSN	Full-key
Denmark	DS	Not known
France	AFNOR	Full-key
Germany	DIN	Full-key since around 1965
Hungary	MSZH	Not known
Italy	UNI	Not known
Japan	JISC	Half-key
Netherlands	NNI	Not known
Romania	IRS	Not known
South Africa	SABS	Not known
Sweden	SIS	Full-key
Switzerland	SNV	Not known
United Kingdom	BSI	Half-key before 01.01.1978, full-key since
USA	ANSI	Half-key

Notes:
Where no introduction date is given, it is to be assumed that no other convention was in force before. In the light of European harmonisation, it can be assumed that many European countries have been using the full-key convention since 01.01.1978.

33.2 New international conventions

The half-key convention was introduced in 1989 with ISO 8821 and adopted as a German standard as DIN ISO 8821 in 1991. 1990 has been set as the year in which this standard will be introduced and become applicable to all machines of this type. A CENELEC harmonisation document (HD) on full-key balancing has been in force since 1978 for rotating electrical machines; this was superseded by a new HD on half-key balancing in 1992. This specified 01.06.1998 as the end of the transitional period for the manufacture of electrical machines with full-key balancing.
The general ISO requirement has been formally implemented with DIN EN 60034-14 / VDE 0530 Part 14 for rotating electrical machines. Technical Group 1 of the ZVEI (Zentralverband der Elektrotechnischen Industrie e.V. – Association of the Electrical Engineering Industry) has informed manufacturers of electrical machines of the end of the transitional period for the full-key convention and has recommended that customers placing orders should be informed accordingly.

33.3 Advantages and disadvantages of the previous full-key convention

Benefits:

- ☐ The shaft is supplied and balanced with the key; the fitting element is balanced without a key. No error caused by incorrect choice of key.
- ☐ No special half-keys required.
- ☐ Any non-conforming keyway lengths on the shaft and fitting element will not cause any damage.
- ☐ Possible to carry out a subjective and objective assessment of the motor in a test run with the key inserted, but without the fitting element.
- ☐ Shaft (with full-key inserted) and fitting element (without key) are balanced when they leave the respective manufacturers.

Disadvantages:

- ☐ An additional imbalance is created in the shaft (protruding key) and the fitting element (keyway) which then has to be corrected at a cost. Depending on the design of the parts, there may be a limit to the amount of mass balancing that can be done.
- ☐ An internal bending moment is generated in the shaft. The protruding part of the key creates an imbalance that must then be compensated for in at least two planes by balancing masses on the shaft (otherwise it is not possible to achieve a balance in the key plane). The internal bending moment can affect the balance of flexible rotors; it does not affect rigid rotors. The internal bending moment remains in the shaft, even after the fitting element has been installed.
- ☐ There is confusion on the world market because individual manufacturers and countries use this method but at the same time use the half-key convention for larger shafts without any properly defined demarcation rule. When components are supplied by two different manufacturers who have used different key conventions, these components will be incompatible.
- ☐ The full-key convention does not allow coupling manufacturers to follow their normal practice of balancing their couplings before incorporating the keyways.

33.4 Advantages and disadvantages of the new half-key convention

Benefits:

- ☐ No additional imbalance in the shaft and fitting element – no unnecessary corrections.
- ☐ No internal bending moments.
- ☐ Fitting elements can – in accordance with the normal practices followed by the manufacturers – be balanced before the keyways.

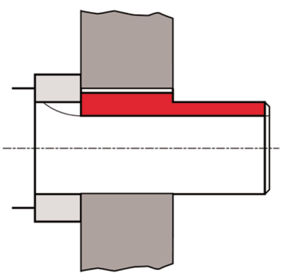
Disadvantages:

- ☐ A special key has to be manufactured for balancing – difficult to manufacture in the case of Woodruff keys, nose keys and sunk keys.
- ☐ Individual balancing incurs additional costs (for example for repairers).
- ☐ Special keys are also required at the installation location if the vibration behaviour without the fitting element is to be measured there.
- ☐ If the key used during assembly is a different length to that used for balancing, an imbalance will arise.

33.5 Adapting the fitting element

Even going on the natural assumption that the shaft and fitting element have to be balanced using the ***same convention*** some fine tuning is still required during assembly at the installation location on account of the shaft and the hub having different lengths.

Figure 33.5.1 ***Stepped keys***



These keys have two sections of different heights.
The method is suitable for individual manual manufacturing procedures.
Because there are so many different variants, stepped keys are not available as standard parts or bought parts.

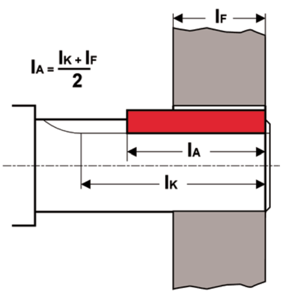
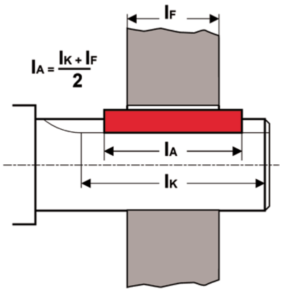
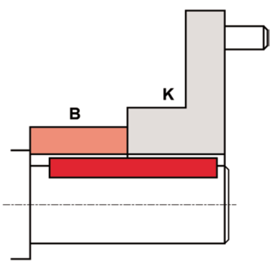
Figure 33.5.2 ***Medium-length keys***	
a)	b)
	
This mounting used in practice is permissible.	The ideal axial mounting for built-in keys which have been shortened to the average lengths of the keyways in the shaft and hub, is the centre of the rectangular section of the shaft keyway. This mounting is very rarely possible in practice.

Figure 33.5.3 ***Compensating sleeve***	
	The "missing" (in comparison with the shaft) length of hub of the fitting element (K) is compensated for by a sleeve (B). This compensating sleeve must be balanced using the half-key method. The sleeve also acts as a spacer and prevents accidents. This method is practised by the big users (for example BASF) as the "works standard". ***It is desirable for manufacturers of fitting elements to include the corresponding compensation sleeves in their product range***.

33.6 Marking and supply convention

The use of half-key balancing must be "permanently" marked near the keyway with the letter "H" – on the end face of the shaft end in the case of motors and on the end face visible after assembly in the case of fitting elements. If the end face of the shaft is too small, the standard specifies the keyway ground as an alternative (highly unsuitable from a practical point of view). The use of full-key balancing has not previously been marked; this practice may continue upon agreement between the customer and the manufacturer. This balancing method is marked by the letter "F" (full-key convention) where necessary. Half-key balancing should have been the standard design for manufacturers of motors and fitting elements since 01.06.1998. ***All special designs which deviate from this must be agreed***.

33.7 Possible assembly faults

Many possible assembly faults will arise from the new balancing convention, particularly during the introductory period. To conclude, here again are the three most obvious faults:

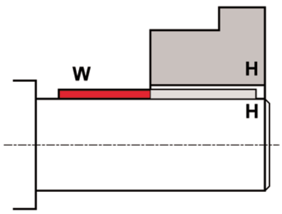


Figure 33.7.1
Fault: Shaft with half-key balancing
Hub with half-key balancing
Protrusion of the key creates unbalanced mass W.

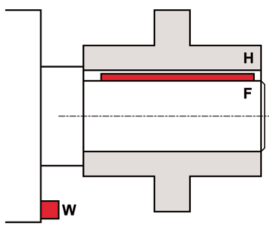


Figure 33.7.2
Fault: Shaft with full-key balancing
Hub with half-key balancing
Key diameter overshoot is balanced on the laminated core by additional weight "W" in relation to the rotor. The balance weight W would be unnecessary for a motor employing the "H" balancing method – this combination would cause an imbalance.

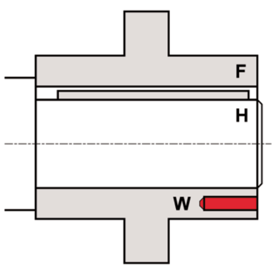


Figure 33.7.3
Fault: Shaft with half-key balancing
Hub with full-key balancing
Missing mass of the balance bore W in the hub would be unnecessary if method H were employed on the fitting element – this combination would cause an imbalance.

34 Electromagnetic compatibility (EMC)

This brief summary relating to electric motors is an extract from the comprehensive Danfoss-Bauer special publication SD 3396.

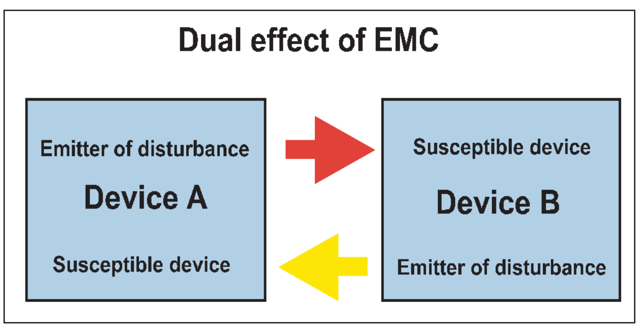
34.1 General

The EMC Directive of the European Community was adopted on the 1st January 1992 into German law as the law on the electromagnetic compatibility of equipment (EMVG). The monitoring body responsible for these matters is the BAPT (Bundesamt für Post und Telekommunikation - Federal office of post and telecommunications).
Electromagnetic compatibility (EMC) is the ability of an electrical device to work satisfactorily in its electromagnetic environment, without unduly affecting this environment to which other equipment also belongs.
The EMC Directive 89/336/EC contains two fundamentally different requirements for electrical (electronic) equipment:

- ☐ *Limiting the* ***interference emissions*** means that a device must not emit unduly high electromagnetic fields into the environment. A computer or drill, for example, should not cause the radio to crackle. The generation of electromagnetic interference must be limited to the extent that makes it possible to operate radio and telecommunications and other equipment properly.
- ☐ ***Interference immunity*** means that a device is protected from electromagnetic fields up to a specific level and that no malfunctions occur, such as the failure of a PLC (programmable logic controller) system, when a radio telephone is used in the immediate vicinity. The equipment must therefore demonstrate a reasonable immunity to electromagnetic interference, so that they can be operated properly.

Each electrical and electronic device is a source of electromagnetic interference and is susceptible to such energy at the same time. Electromagnetic compatibility can only be achieved by both limiting interference and ensuring interference immunity.

Figure 34.1
Duality of EMC



34.2 Induction motors

Electrical immunity measurements on induction motors are not necessary because the motors cannot be affected either by electromagnetic radiation or conducted interference (the power transmitted is much too low). Likewise measurements of irradiated high-frequency electromagnetic fields and conducted high-frequency voltages do not have to be carried out either because induction motors do not contain any mechanical or electronic switches or resonant circuits which might cause this sort of interference.
Three-phase motors generate mains harmonic currents. These particularly occur when starting. However, the manufacturer can keep the harmonic currents very low by adopting specific design measures (slot skewing, coil chording, stator/rotor slot number ratio).
Standard EN 61000-3-2 (class A) specifies mains harmonic current limits for motors with a rated current of up to 16 A which are operated on a public low-voltage network. If starting occurs in less than 10 s, which is practically always guaranteed, a measurement in a steady-state condition at nominal load is sufficient.
Motors with a higher rated current are normally operated on an industrial network. This may require consultation with the power supply companies. Standards IEC 1000-3-4 and IEC 1000-3-5 provide appropriate information.

34.3 DC motors (commutator machines)

As on induction motors, interference immunity measurements on DC machines are not necessary. Conducted interference is not measured on the direct-current side, but between the control system and the low-voltage network. Conducted interference on a motor cable, i.e. between the control system and the machine, is not subject to any restrictions by standards.
With regards to the emission of high-frequency electromagnetic fields, there is in practice a great difference between low power DC motors, which are normally designed without commutating poles and compensating windings, and medium and high-power machines. Assuming that the brushes are well run-in and that commutation does not create any sparks (film), practically no radio interference will occur with DC machines with commutating poles and compensating windings, with the result that these meet the EMC limits without any further measures being required.
DC motors ***without commutating poles*** can cause considerable radio interference, even if no sparks can be seen during the commutation process. Particularly critical are motors with permanent magnets, because the air gap at the edge of the main poles is not normally widened, which makes commutation even worse.
For information on suppression measures, see Danfoss Bauer special publication SD 3396.

34.4 Example of a declaration of EC conformity

Danfoss Bauer GmbH
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Telefon (0711) 3518 0
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Homepage: www.danfoss-bauer.de

EC Declaration of conformity

(in accordance with EC Directive 89/336/EEC)

Document No./
Month, Year: **EK 07 - 07/99 E**

We declare at our sole responsibility that the products

Geared motors of the series

Three-phase : D04, D05, D06, D08, D09, D11, D13, D16, D18, D22, D25, D28

Single-phase : E04, E05, E06

fulfil the requirements specified in the Council's directive concerning the harmonisation of the member states' statutory provisions regarding electromagnetic compatibility (89/336/EEC).

This declaration only applies under the following conditions:

The products must be connected directly to an industrial three-phase mains (for motors of E.. series: a.c. system) or to a frequency inverter from the manufacturer Danfoss Antriebstechnik GmbH.
The information on installation provided in the operating instructions for the geared motor and, where appropriate, the frequency inverter must be followed.

Clear reference is made in the operating instructions for the products to this restriction.

The following standards have been used to assess the electromagnetic compatibility of the products:

DIN EN 50081 - 2	1993	Basic specification	Emitted interference
DIN EN 50082 - 2	1995	Basic specification	Noise immunity

Esslingen, 1st July 1999 EE-dop/wz

Danfoss Bauer GmbH

ppa Doppelbauer i.V. Fuchs

ppa. Dr.-Ing. Doppelbauer (Manager EE)

i.V. Fuchs (Manager QA)

This declaration provides no guarantee of characteristics.

The safety information in the product documentation supplied must be observed.

BAUER geared motors

Erfüllungsort und Gerichtsstand: 73734 Esslingen Sitz: Esslingen-Neckar Registergericht: Amtsgericht Esslingen HRB 3759
Ust-IdNr.: DE812722413 Geschäftsführer: Karsten Moe

VII MEASUREMENT AND EVALUATION OF TEMPERATURE RISE

35 Temperature rise process

The heat rise in an electrical machine is an important measure for the assessment of the machine's operating properties and for estimating its service life.

35.1 Temperature rise in the case of continuous running duty S1

Compared with most other energy converters, electrical machines have a very good level of efficiency η; the unavoidable losses P_V heat up the machine relative to the ambient (**Figure 35.1**).

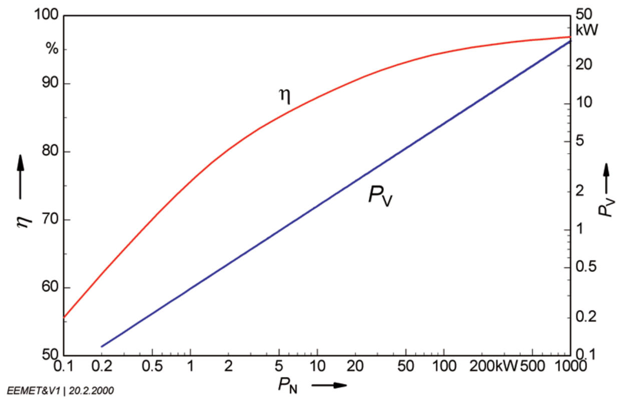


Figure 35.1
Guide values for the efficiency η and the losses P_V of three-phase cage motors with rated outputs of 0.1 ... 1000 kW

Under the idealised assumption that a body is homogenous, the following applies for a specific period of time

Generated heat	=	Stored heat	+	Dissipated heat
$P_V \cdot \Delta t$	=	$c \cdot m \cdot \Delta\vartheta$	+	$\alpha \cdot O \cdot \Delta\vartheta \cdot \Delta t$

P_V – Power loss
Δt – Time period
c – Specific heat capacity of the body to be heated up
m – Mass of the body to be heated up
$\Delta\vartheta$ – Temperature difference between body and coolant
α – Heat transfer coefficient
O – Heat-radiating surface of the body.

At the start of the heating phase, the heat is initially entirely and then primarily stored in the mass of the body to be heated up; as the temperature rises it is increasingly, and in the steady-state condition entirely, dissipated to the coolant by radiation and convection.

35.2 Heat rise time constant

The heat rise time constant describes the heat properties of the “body” (the machine) as a ratio of
heat capacity C to heat transfer capability A:

$$\tau = \frac{C}{A} = \frac{c \cdot m}{\alpha \cdot O}$$

Figure 35.2 shows the graph for the heat rise process for two machines with different heat rise time constants that are typical for specific types of machines. Because an electrical machine and its different components is not “homogenous”, the actual heat rise process will differ, sometimes considerably, from this schematic representation.

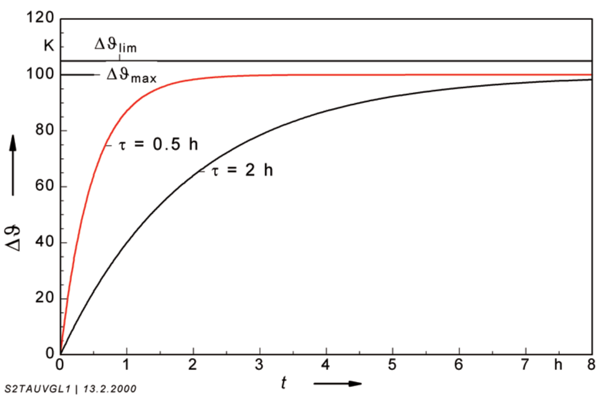


Figure 35.2
Schematic diagram of the temperature rise

τ = 0.5 h:
Relatively small and/or well ventilated machines

τ = 2 h:
Relatively large and/or poorly ventilated machines

36 State of equilibrium in the heat rise process

The ***thermal state of equilibrium*** is defined in the standard; it determines the duration of the heat rise process for measurement under test conditions. The estimate of the anticipated duration of the load can be useful for in-service measurement at the installation location.

36.1 Theoretical heat rise graph

The following function applies to the temperature rise of an electrical machine under simplified assumptions and constant conditions (load, ventilation, ambient temperature):

$$\Delta\vartheta = \Delta\vartheta_{max}\left(1 - e^{-\frac{t}{\tau}}\right)$$

$\Delta\vartheta$ – Temperature rise in K
$\Delta\vartheta_{max}$ – Maximum temperature rise when there is a balance between heat input and cooling
t – Load time
τ – Time constant (C/A ratio = Heat capacity / heat transfer capability)
e – Natural logarithm (approx. 2,72)

The equilibrium temperature $\Delta\vartheta_{max}$ of the machine must not exceed the temperature rise $\Delta\vartheta_{limit}$ specified for its temperature class in EN 60034-1. The time constant τ is long if the machine is large and/or relatively poorly ventilated. It is relatively short in the case of small and/or well ventilated machines.

36.2 Duration of the heat rise process for S1

The analysis of the exponential function in section 36.1 showed that after completion of three time constants τ a temperature approximately 95 % of that of the equilibrium temperature was reached (**Figure 36.2.1**). However, because in practice the time constant of a specific motor is not generally known, the end of a heat rise process must be determined using other criteria.
Because the temperature rise is "asymptotic", EN 60034-1 (VDE 0530 Part 1) stipulates in 2.11 that the "thermal state of equilibrium" is considered to have been reached if the temperature rises of the different machine parts change by a maximum of 2 K over a period of one hour (**Figure 3.2.2**).
When assessing the thermal capacity in practical operation, such strict measures do not have to be applied. Guide values for the duration of the heat rise process can be found in **Figure 36.2.3**.

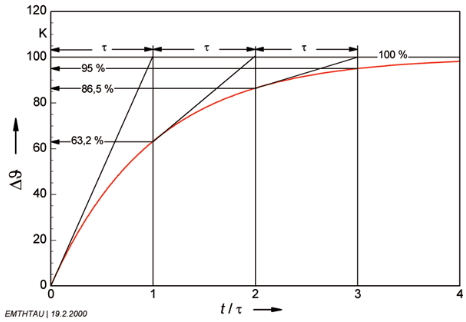


Figure 36.2.1
Analysis of a theoretical heat rise process after completion of the time constants τ

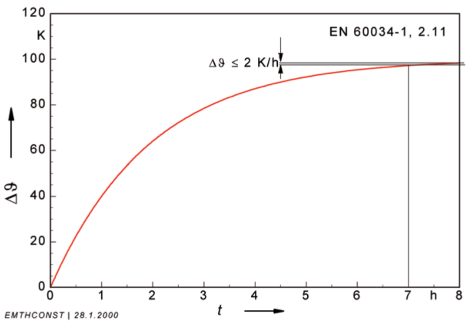


Figure 36.2.2
Definition of the “thermal state of equilibrium”

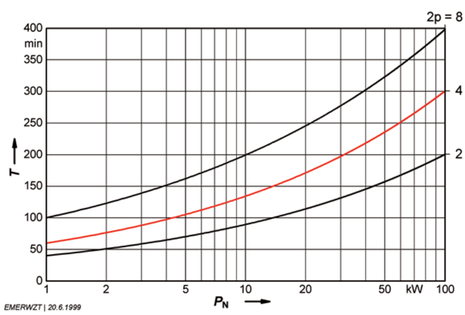


Figure 36.2.3
Guide values for the duration T of the heat rise process of three-phase motors with rated outputs P_N and 2, 4 and 8 poles

36.3 Calculation of temperature rise in copper

The ***resistance method*** as specified in section 7 in EN 60034-1 (VDE 0530 Part 1) is used to calculate the temperature rise in copper.
The temperature rise $\Delta\vartheta = \vartheta_2 - \vartheta_a$ is calculated as follows:

$$\Delta\vartheta = \vartheta_2 - \vartheta_a = \frac{\vartheta_2 + k}{\vartheta_1 + k} = \frac{R_2}{R_1}$$

$\Delta\vartheta$ Temperature rise in K
ϑ_1 Temperature of the cold winding after the first measurement in °C
ϑ_2 Temperature of the winding at the end of the heat rise test in °C
ϑ_a Temperature of the coolant at the end of the heat rise test in °C
R_1 Resistance of the winding at temperature ϑ_1 (cold)
R_2 Resistance of the winding at the end of the heat rise test
k Reciprocal value of the temperature coefficients of the resistor at 0 °C
for copper k = 235 K
for aluminium k = 225 K, unless otherwise specified.
After conversion, the temperature rise can be calculated from the equation

$$\Delta\vartheta = \vartheta_2 - \vartheta_a = \frac{R_2 - R_1}{R_1} \cdot (k + \vartheta_1) + \vartheta_1 - \vartheta_a$$

Temperature rise limits in accordance with Table 1 of EN 60034-1 (VDE 0530):

No.	Type of machine	Thermal classification		
		B	F	H
1c)	$P_N < 600$ W	85 K	110 K	130 K
1d)	600 W $\geq P_N \leq$ 200 kW	80 K	105 K	125 K

If a comparison is made between ***temperature rise limits*** and the ***permissible permanent temperatures*** assigned to a temperature class, differences of 10 ... 15 K are evident. This is necessary because the temperatures rises have been calculated from the copper resistance and therefore represent a mean value along the length of the winding. The ***hottest spot*** of a winding is hotter and is at different locations, depending on the type of cooling the machine has (**Figs. 36.3.1** and **36.3.2**).

Thermal classification	B	F	H
Temperature rise	80 K	105 K	125 K
Ambient temperature	40 °C	40 °C	40 °C
Overall temperature	120 °C	145 °C	165 °C
Limit of insulating material	130 °C	155 °C	180 °C
Reserve for hottest spot	10 K	10 K	15 K

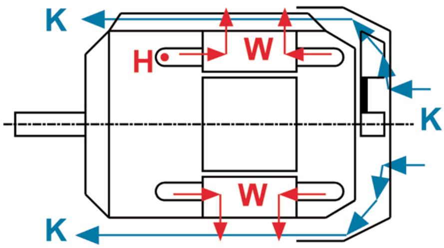


Figure 36.3.1
Heat flow (W), cooling air flow (K) and hottest spot (H) on surface-ventilated machines (e. g. IC411, IC416)

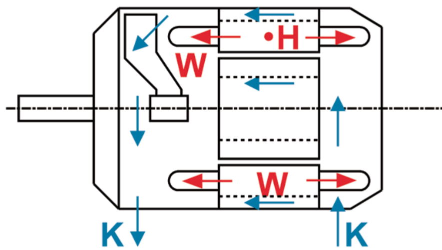


Figure 36.3.2
Heat flow (W), cooling air flow (K) and hottest spot (H) on open-circuit air-cooled machines (e. g. IC01, IC06)

36.4 Duration of the heat rise process for periodic operation (S3 ... S8)

During the test the specified load cycle must be applied and repeated until practically identical temperature cycles are achieved. The criterion for this is when an imaginary straight-line drawn between the corresponding points of the temperature cycles has a gradient of less than 2 K per hour. If necessary measurements should be carried out over one load cycle at reasonable intervals. In the last load cycle, the temperature rise in the middle of the time period showing the greatest heat rise must not exceed the limits stated in Table 1 of EN 60034-1 (found in section 3.2.3) (**Figure 36.4**).

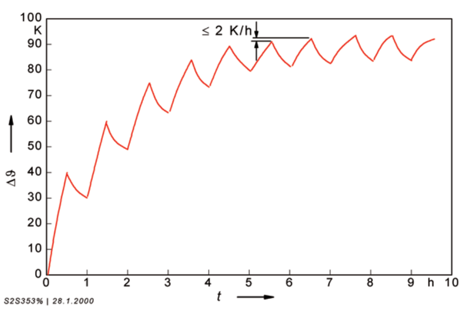
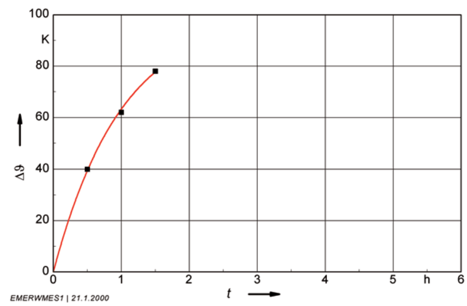


Figure 3.4
Criterion indicating that the thermal equilibrium temperature has been reached for periodic duty type S3 ... S8

36.5 Estimate following an interruption in the heat rise process

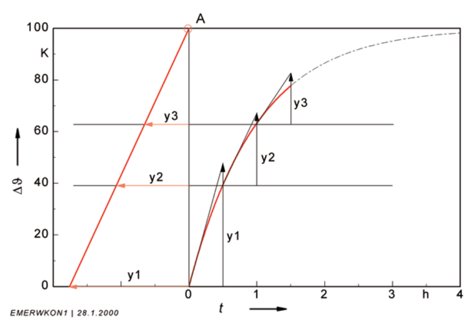
If, in exceptional cases, it is not possible to wait for the periods specified in section 36.2 for the end temperature to be reached, the following approximation method can be used: At the beginning of the test run, the machine must be at ambient temperature. The operation of the machine should be interrupted at regular intervals (e. g. every ¼ or ½ hour) for as short a time as possible, in order to measure the winding resistance. The copper temperature rises calculated from this (e. g. measurements 1, 2 and 3) are plotted in accordance with **Figure 36.5.1** and joined with a suitable graph. In the example, the test run lasted 1½ hours.

Figure 36.5.1
Plotting of three measurements from a test run commenced at ambient temperature and shortened to 1½ hours



Tangents for the gradients are now placed on the graph at the time intervals of ½, 1 and 1½ hours. The gradients *y*1, *y*2 and *y*3 (if necessary enlarged by a standardised factor *k*) are plotted on the left of the y axis as per **Figure 36.5.2**. If the ends of these three arrows are now joined and the straight-line extended along the *y* axis, it intersects the anticipated final temperature rise value at point A (in the example 100 K).

Figure 36.5.2
Calculating a guide value for the end temperature rise value “A” from the measurements taken from a test run shortened to 1½ hours



37 Cage temperatures

The excess temperature of permanently short-circuited windings may never reach such values as to endanger the insulation or adjacent components (EN 60034-1, Table 1; item 5). The effect on the stator winding is detected by the extent to which it heats up. The loading on adjacent rolling contact bearings is to be measured separately if necessary. The temperature in the cage itself is to be determined, especially in the case of explosion-proof machines in type of protection EEx e or in the event of brief loading on the rotor – e. g. in the case of heavy starting or a stalled rotor.

37.1 Continuous running duty S1

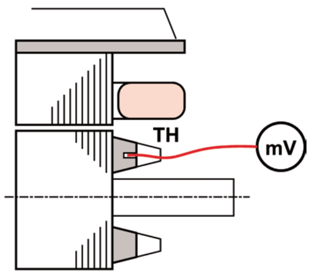


Figure 37.1.1
Thermo-element in the end ring

Temperature differences between the bar and ring largely balance one another out in continuous running duty; it is thus sufficient to partially dismantle the motor to fit a thermo-element which can be inserted in a (possibly previously prepared) small bore in the ring (**Figure 37.1.1**). Since a certain time passes after switching off (e. g. around 30 seconds in **Figure 37.1.2**) until the first measured value becomes available, the series of measurements then noted or plotted is extrapolated to the time of switching off. A contact thermometer may also used if the requirements on measuring accuracy are not too demanding and if the contact face is clean.

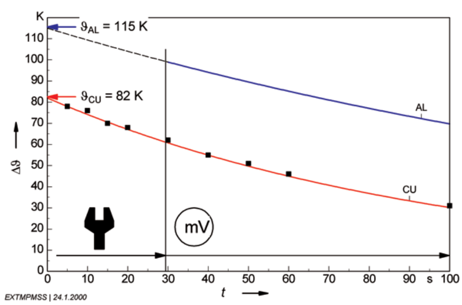


Figure 37.1.2
Extrapolation of the heating values in the end ring (AL) for the determination of heating at the time of switch off ϑ_{AL}

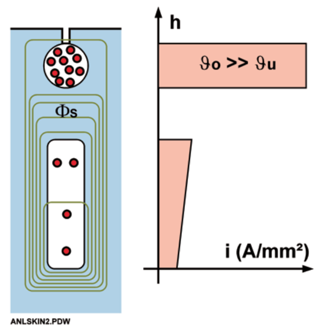
Copper heating ϑ_{CU} can be determined from a resistance measurement after just 5 sections, as the terminals are easily accessible

Where the demands on measuring accuracy are not too great (i.e. ***not*** in the course of an acceptance test, for instance), temperature indicators may also be affixed to the end ring and read after removal under no time pressure. This method is also recommended if the requirement is to demonstrate that thermal overloading has taken place (e. g. during a night shift) (Section 37.3).

37.2 Stalling

Since incomplete heat equalisation occurs during the limited time of a locked rotor or heavy starting (e. g. in the region of 5 ... 30 s), the bars of a cage can become substantially hotter than the rings. Rotors with a distinctive current displacement or skin effect (deep or double slots, **Figure 37.2.1**) are particularly at risk.

Figure 37.2.1
Double slot with distinctive skin effect in the top bar in the case of a locked rotor or starting; correspondingly great temperature difference between top bar ϑ_o and bottom bar ϑ_u



The rotor must therefore be fitted with thermo-elements in the bar and ring for the locked rotor test; a small groove on the keyway slot accommodates the line for the thermo-element which passes up to half the axial length (**Figure 37.2.2**). Contact thermometers are not suitable for the locked rotor test because of the relatively long thermal response times.

Figure 37.2.2
Arrangement of thermo-elements TH 1 ... 3 in the slot and ring of a cage rotor for the determination of heating in the locked rotor test; two TH arranged offset against one another are used in the test procedure to prove explosion-protection

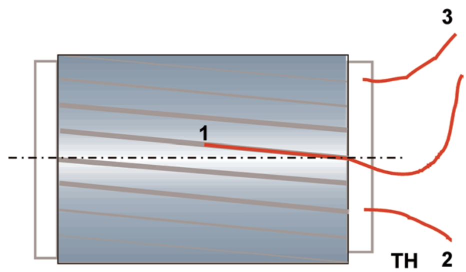


Figure 37.2.3 illustrates the temperature increase in the stator and rotor during the locked rotor test. The thermo-element in the ***stator winding*** was only provided as an additional test point; it is not required for the acceptance test. The delayed temperature graph W-T is intended only to show that direct measurement with thermo-elements provides no usable results for the stator winding because of the thermal insulation.

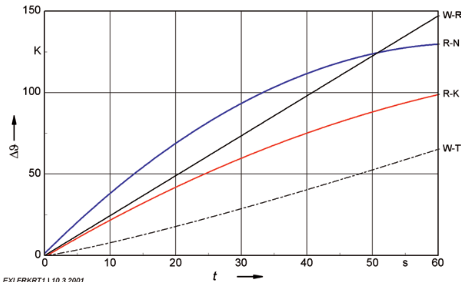


Figure 37.2.3
Temperature increase in the stator and rotor of a “rotor-critical” three-phase cage motor during the locked rotor test.
Test points:
R-N : Rotor bars
R-K : End ring
W-T : Stator winding with thermo-element (unsuitable)
W-R : Stator winding with resistance method

37.3 Temperature indicators

In the case of some problems with drives, measurements should be taken over a longer period to determine whether a limit temperature is reached or exceeded without the drive being constantly monitored or measured by specialist personnel. Temperature indicators which may be cemented to the location to be measured – e. g. the end ring of a cage motor – are useful. The fact that the temperature has been exceeded is indicated by an irreversible colour change from white to black. An adhesive strip with a printed temperature scale covers ranges of 50 or 20 °C in 10 graduations, for instance. The temperature range to be anticipated should, therefore, be roughly estimated beforehand, or a number of strips with adjacent ranges need to be used. The manufacturers give the measuring tolerance as approx. ± 1 %. The standard graduation is 4 ... 6 °C, for instance, there are also sub-ranges with a graduation of 2 °C. Indicators for the temperature range 38 ... 260 °C are available.

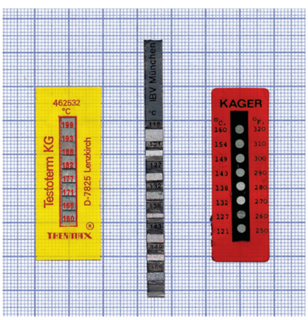


Figure 37.3.1
Examples of temperature indictors by various manufacturers

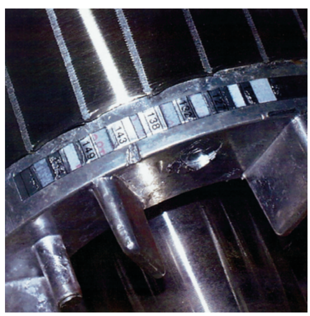


Bild 37.3.2
Temperature indicators on the end ring before fitting

38 Determining the level of utilisation

The issue of the actual utilisation of a drive motor arises when a equipment prototype is being tested or if a tried and tested equipment is to be revised and optimised.
This section gives a few suggestions as to how to calculate the actual motor utilisation in practice.

38.1 Manufacturer's load characteristics

Danfoss Bauer produces ***load characteristics*** similar to **Figure 38.1.1** and **Figure 38.1.2** as part of type testing.

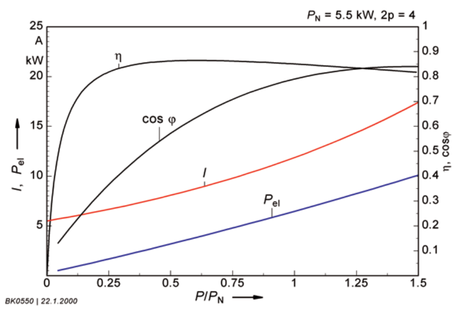


Figure 38.1.1
Typical load characteristics of a 4-pole three-phase asynchronous motor, rated output 5.5 kW

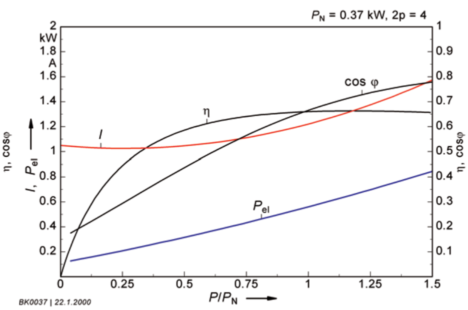


Figure 38.1.2
Typical load characteristics of a small three-phase asynchronous motor, rated output 0.37 kW

On small-power motors (e. g. P_N < 0.37 kW) the current characteristic graph I is so flat that it is not suitable for an assessment of the level of load. In these instances, power consumption P_1 should be used instead (Figure 38.1.2).
Characteristics of this type have been plotted by the manufacturer using a precisely controlled rated voltage. They are only meaningful in the determination of the actual output based on the measurement of the current consumption if the rated voltage (across the motor‘s terminals!) deviates only slightly from the setpoint value when the measurements are conducted at the site of use. Tolerances of approximately ± 3 % appear to be permissible in this context.
The permissible voltage fluctuations of ± 5 % in "range A" or ± 10 % in "range B" quoted in IEC 60034-1, subclause 12.3 relate to the function of the motor only and not to the often considerable influence on the shape of the current characteristic graph which is, in fact, decisive in the calculation of the output.

If it is not possible to keep to a voltage tolerance of around ± 3 % at the installation location, the **power consumption P_1** should be used for the assessment instead of current consumption *I* because power consumption changes only slightly in normal mains voltage fluctuations. Load characteristics of the type shown in Figures 38.1.1 and 38.1.2 for normal production motors (standard motors) should generally be available from the manufacturer. When requesting this information, please quote the ***serial number*** of the motor in question as motors are often manufactured with different winding designs under the same type designation and this will have an effect on the load characteristics. If the load characteristics are not available from the manufacturer – for example because the type series is no longer on the market – the following methods are used.

38.2 Power consumption

The effective power consumed at no-load P_0 covers the losses incurred; these are mainly no-load core losses, friction and fan losses, no-load copper losses. It can be calculated relatively easily with the driven machinery disconnected and if the rated voltage deviates as little as possible (e. g. ± 3 %). Another important point on the characteristic graph is the power consumption P_1 at rated output P_N; this value can be calculated from the information given on the rating plate:

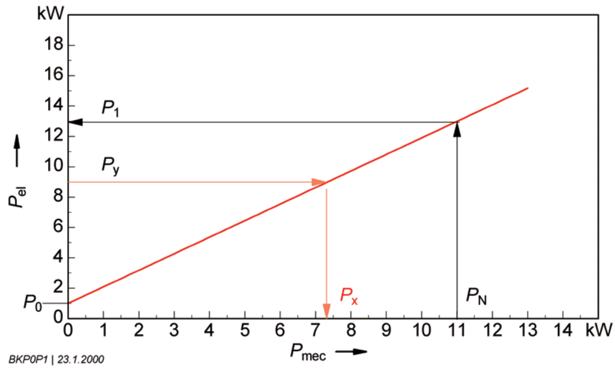
$$\eta = \frac{P_N \cdot 1000}{I_N \cdot U_N \cdot \sqrt{3} \cdot \cos\varphi} \qquad P_1 = \frac{P_N}{\eta}$$

P_1	Power consumption at rated point in kW
η	Efficiency as a decimal fraction
P_N	Rated power in kW
I_N	Rated current in A
U_N	Rated voltage in V
$\cos\varphi$	Power factor

The data in the shaded box can be found on the rating plate.
The pattern of the characteristic graph between P_0 and P_1 is virtually linear, (see Figs. 38.1.1 and 38.1.2).
For a rough estimate, a linear pattern in accordance with Figure 38.2.1 can be assumed. It is then relatively easy to calculate the output P_x for a consumption P_y, with a safety margin of 10 % intended to take account of the actual curvature of the characteristic graph.

Figure 38.2.1
Simplified power graph for rated output
$P_N = 11$ kW

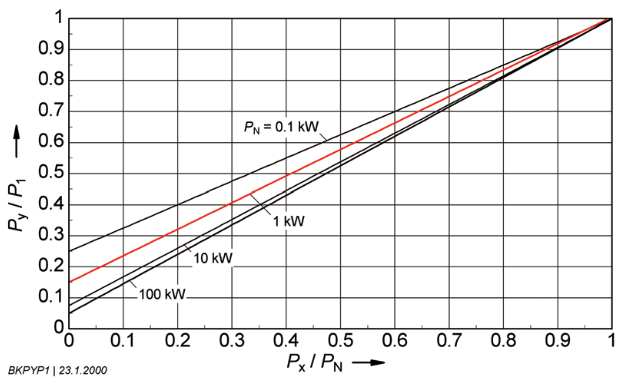
Calculation of actual output P_x from the measured consumption P_y



P_{el} – Electrical power input
P_{mec} – Mechanical power output
P_0 – No-load power input
P_1 – Power input at rated output

Some driven machinery cannot be disconnected – therefore the value P_0 cannot be measured. In these cases, the empirically calculated set of characteristics as per **Figure 38.2.2**, will help; however, as a result of the assumptions that have to be made, this will lead to a somewhat larger error in the output estimate.

Figure 38.2.2
Empirically calculated set of characteristics for relative power consumption P_y / P_1, if the value P_0 / P_1 has to be estimated



P_N – Rated mechanical output
P_1 – Power input at rated output
P_y – Actual input
P_x – Actual output

Example (Figure 38.2.3):

Plate data	P_N	=	1.5	kW
	I_N	=	3.7	A
	U_N	=	380	V
	$\cos\varphi$	=	0.82	
Measurement	P_y	=	1200	W
Assumption	P_0 / P_N	≈	0.14	

(see parameter for rated output in Figure 38.2.3)

Calculation

$$\eta = \frac{P_N \cdot 1000}{I_N \cdot U_N \cdot \sqrt{3} \cdot \cos\varphi} =$$

$$\frac{1{,}5 \cdot 1000}{3{,}7 \cdot 380 \cdot \sqrt{3} \cdot 0{,}82} = 0{,}75$$

$$P_1 = \frac{P_N}{\eta} = \frac{1500}{0{,}75} = 2000 \text{ W}$$

Evaluation in accordance with 38.2.3

P_y / P_1 = 1200 / 2000 = 0.6
P_x / P_N = 0.54
P_x = 1.1 · 0.54 · 1,5 ≈ 0.9 kW
(with 10 % margin)

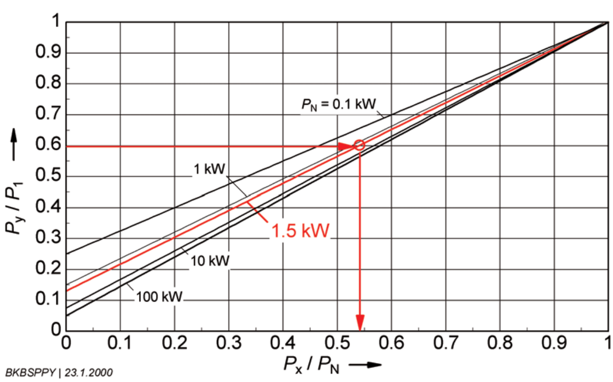


Figure 38.2.3
Example of an application of a set of characteristics in accordance with Figure 38.2.2 for a motor with a rated output of 1.5 kW

38.3 Simplified current characteristic graph

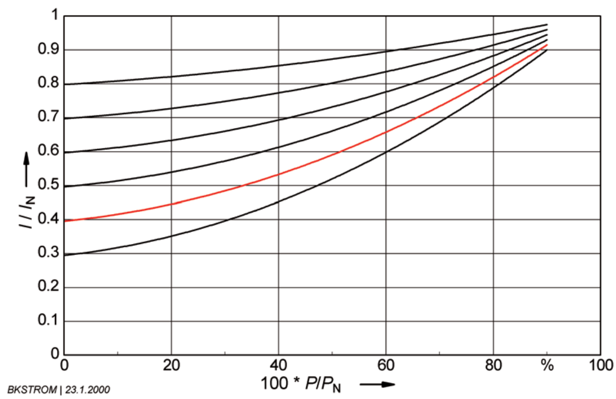
If it is not possible to measure the power consumption at the installation location and only the current consumption can be calculated, it is also possible to estimate the power output - albeit with greater results uncertainty.

To be measured are: I_0 – No-load current at rated voltage ± 3 %

I_x – Actual current consumption at the load point.

Figs. 38.1 and 38.2 show that no linear pattern can be assumed for the current characteristic graph between no-load and the rated output. The relative no-load current I_0 / I_N is greater the smaller the motor and the higher the magnetic saturation. Typical relative current characteristic graphs are shown in Figure 38.3.1 with this parameter (I_0 / I_N). At I_0 / I_N values > 0.8 the characteristic graph becomes so flat that this method leads to very uncertain results – the power measurement is to be preferred in this case.

Figure 38.3.1
Simplified relative power consumption I / I_N as a function of relative output P / PN for parameters I_0 / I_N = 0.3 ... 0.8



Example for the evaluation (Figure 38.3.2):

Plate data	P_N	=	15	kW	
	U_N	=	400	V	
	I_N	=	30	A	
Measurement	I_0	=	13.5	A	
	I_x	=	19.5	A	
Calculation	I_0 / I_N	=	13.5/30	=	0.45
	I_x / I_N	=	19.5/30	=	0.65

Evaluation: The estimated highlighted characteristic graph applies for the parameter $I_0 / I_N = 0.45$; from $I_x / I_N = 0.65$ is produced $P_x / P_N = 0.54$

Output P_x = $0.54 \cdot 15 \approx$ 8 kW

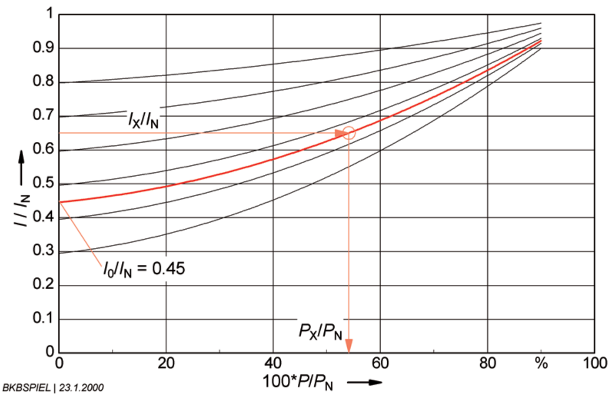
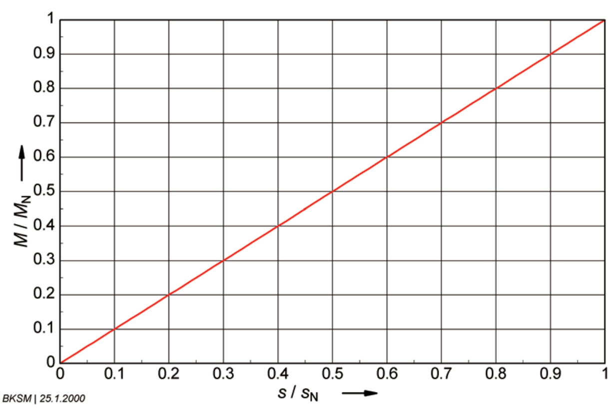


Figure 38.3.2
Example of an evaluation using the simplified characteristic graphs in accordance with Figure 38.3.1

$I_0 / I_N = 0.45$
$I_x / I_N = 0.65$
$P_x / P_N = 0.54$

38.4 Slip

If the torque characteristic graph is shown in “American” style, as in **Figure 38.4.0.1** it demonstrates the almost linear reduction in speed as torque increases (both parameters shown relative to each other). The speed drop or slip s, relative to synchronous speed should therefore be a simple and good indicator of relative loading (**Figure 38.4.0.2**).



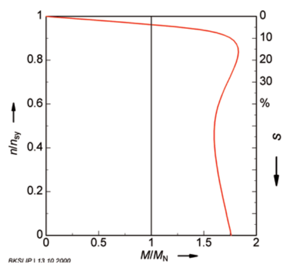


Figure 38.4.0.2
Utilisation factor M/M_N as a function of slip s
n/n_{sy} – Relative speed
M/M_N – Relative torque

Figure 38.4.0.1
Torque – speed – characteristic graph
s – Slip

Although it sounds tempting to be able to calculate the utilisation factor of an induction motor using a simple speed measurement - there are some serious limitations and reservations:

- ☐ How “accurately” can slip be calculated?
- ☐ How “accurate” is the rated speed shown on the plate?

38.4.1 Display tolerance of speed counters

If slip is calculated indirectly from a measurement of speed, the display and reading tolerance of the measuring equipment plays an important role:

Example:	Real speed value	1450 r/min
	Reading	1455 r/min
	Deviation	0.34 %
	Real value for slip speed	50 r/min
	Reading	45 r/min
	Deviation	10 %

Already the relatively “accurate” speed counter, with a deviation of just 0.34 %, is responsible for a relatively high uncertainty of around 10 % when estimating the utilisation factor. From the outset, therefore, speed measuring methods with an error of > 0.1 % are ruled out for calculating power by means of slip. What display and reading tolerances can be expected on proprietary speed counters?

38.4.1.1 Dynamo with analogue display (tachometer)

A temperature-compensated eddy-current measuring mechanism generates a voltage which is directly displayed on a calibrated scale as speed. The manufacturers give the measuring tolerance as approx. ± 0.5 ... 1 % (as usual with respect to the full-scale deflection). High levels of reading errors often occur as well (for example because of the coarse scale divisions or on account of vibrations). This measuring principle is too inaccurate for the task in hand.

38.4.1.2 Revolution and time counting

Better values can be obtained by measuring the number of revolutions over a specific period of time – if possible in a device that records both values. However, in this instance, the speed must be constant during the measuring period, which can be assumed for continuous running duty without load fluctuation. The manufacturers state a deviation of (0.2 ... 0.5) % for these “speed stop watches”.

38.4.1.3 Handheld tachometers with digital displays

These devices optically record a mark on a rotating part; they have a tolerance of 0.1 % or ± 1 digit.

38.4.1.4 Stroboscopes

The particular advantage of this principle is that it enables the processes at a rotating part to be visualised. However, the stroboscope‘s display tolerance of ± 1 % or ± 1 r/min, means that it does not meet the requirements for the matter in question here.

38.4.1.5 Direct slip measurement
This method produces the least deviation. A ring-shaped “slip coil” (e. g. 700 turns of round wire of approximately 1 mm ∅, average turn diameter of 20 ... 30 cm) is applied axially directly to the motor. The leakage fields being emitted induce a voltage which can be recorded by a moving coil instrument. This voltage contains the supply frequency (which a moving coil instrument cannot follow) and the superimposed slip frequency the excursions to one side of which (periods) are to be counted.
The pointer deflection can still be calculated visually for slip up to around 6 % (slip frequency of around 3 Hz); the following formula is used in this case:

$$s = \frac{Z \cdot 100}{T \cdot f}$$

s – Slip in %
Z – Number of excursions (in one direction)
T – Time taken for Z excursions in s
Z / T – Slip frequency in Hz
f – Supply frequency in Hz

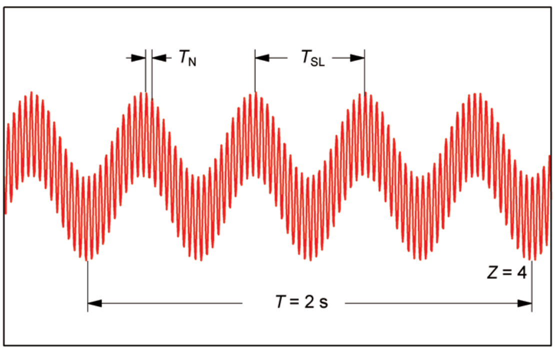


Figure 38.4.1.5
Oscillogram of induced voltage in a “slip coil” (General representation)

BKSLIPMS I 13 10 2000

Beispiel : $Z = 4$
$T = 2$ s
$f = 50$ Hz

$$s = \frac{4 \cdot 100}{2 \cdot 50} = 4\%$$

38.4.2 Tolerances for rated speed

In order for the slip method to produce a calculation of the level of utilisation of a motor that is usable, the speed and slip information given on the rating plate would need to have narrow tolerances. This precondition is generally not met! According to IEC 60034-1, Table 8, No. 5, the following deviations are permitted for slip in induction motors at rated output and at operating temperature:

Machines	≥ 1 kW	(or kVA)	: ± 20 %
Maschinen	< 1 kW	(or kVA)	: ± 30 %

Expressed in actual figures, this means the following:

Rated output	7.5 kW	0.75 kW
Plate data	1450 r/min	1400 r/min
Permissible deviation	1440 ... 1460 r/min	1370 ... 1430 r/min

A look in manufacturers catalogues shows that the standardised tolerances are to a large extent being used up: In the lower and medium power ranges, most rated speeds are given in multiples of 5 r/min, for example, 1450 or 1455 r/min, but not 1452 r/min. Sometimes they are even graded in multiples of 10 r/min. Because slip and relative torque have a direct linear correlation, a deviation of around ± 20 % must be expected for a level of utilisation calculated using the slip method, if the rated speed stated on the rating plate has been kept to within the limits specified in the standard. The effects of temperature can increase this deviation even further.
If this large error probability is acceptable for carrying out rough estimates, then the "slip method" is a simple method for determining the utilisation factor.

38.5 Direct torque measurement

Torque measuring shafts utilising a variety of methods are available for direct measurement of the torque that is transmitted from the motor to the driven machinery. These include, for example:

- ☐ Strain gauges with frequency-modulated signal transmission
- ☐ Strain gauges with signal transmission via slip rings
- ☐ Inductive recording of torsion

Measurement error is very low, e. g. 0.1 %.

These methods are suitable for laboratories and production testing; for measurements at the installation location, they have one serious disadvantage: ***The shaft assembly has to be separated so that the torque pick-up can be fitted (Figs. 38.5.1 and 38.5.2).***

Apart from special cases, this method is hardly ever used for determining the level of utilisation of small and medium-sized machines.

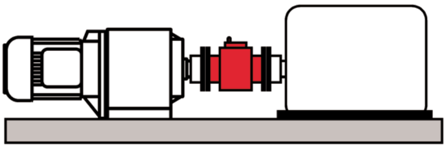


Figure 38.5.1
Location of a torque measuring shaft in the shaft assembly between the drive and the driven machinery

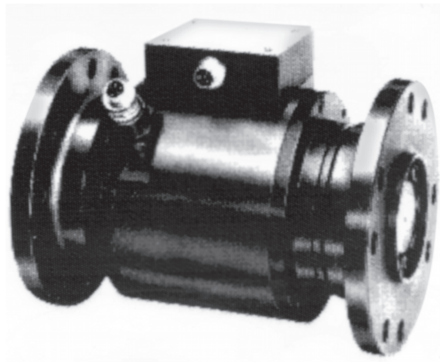


Figure 38.5.2
Flange-design torque measuring shaft for installing in the shaft assembly (STAIGER-MOHILO)

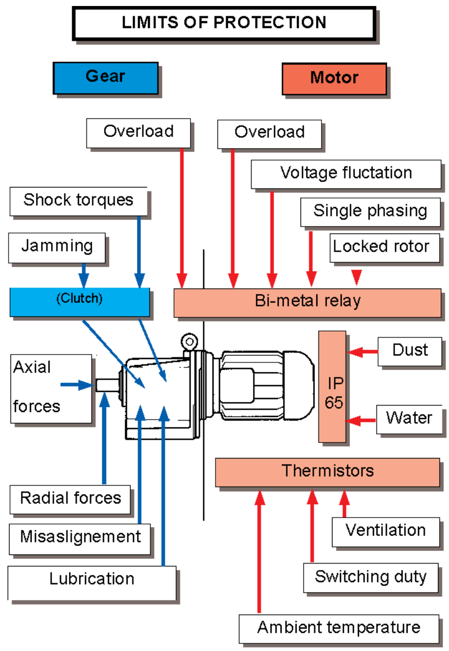
38.6 Conclusion

The question of a motor‘s level of utilisation is being raised quickly and more and more frequently – the answer, however, is often not very easy. This section presented simple measuring and calculation methods suitable for practical applications; however they are limited to duty types S1, S2 and S3.
For switching duty, where the starting cycle has an influence on thermal load (S4 for example) other or additional measurements are required.

VIII OVERLOAD CAPACITY AND OVERLOAD PROTECTION

39 Protection provisions for the geared motor

The increased current drawn in many cases of overloading of the ***motor***, such as mechanical overload, overvoltage, undervoltage, frequent switching, stalling, single-phasing, leads to an excessive winding temperature rise. There are other instances where the winding carries the normal rated current but can still be at risk: e. g. when the ambient temperature becomes excessive or the flow of cooling air is reduced, or inverter duty at low frequency. The type of hazard and the degree of protection desired will determine which of the various methods of protecting the motor windings described below should be selected. In certain applications it may even be necessary to use a combination of two different protective devices. Unlike for the motor, the protection provisions for the ***gear unit*** are significantly limited, and the rate of damage is correspondingly high. You will find full information on this topic in the Danfoss-Bauer book “Protective measures for three-phase geared motors”.



39.1 Overload capacity of the motor

The following is specified in subclause 18.1 of EN 60034-1 (VDE 0530 Part 1) in respect of ***occasional current overloading*** of the windings in cage motors: “Three-phase motors ... must be able to withstand a current equal to 1.5 times the rated current for at least 2 minutes”. A note adds by way of explanation: “The current overload capacity of rotating machines is specified here so that control and protection devices can be configured for the machine. Tests to determine overload capacity are not required by this standard. An approximate calculation of the degree of heating of the motor‘s windings is obtained by multiplying the time by the square of the current. Overcurrent causes increases in temperature. Unless otherwise agreed between manufacturer and customer, it may be assumed that the machine will only be operated at the overcurrents stated for few brief periods over its entire service life.”

Subclauses 19.1 and 19.2 of the standard require, for the ***short-term torque overload capacity*** the following:

Polyphase induction motors for general purose

The motors shall, whatever their duty and construction, be capable of withstanding for 15 s, without stalling or abrupt change in speed (under gradual increase of torque), an excess torque of 60 % of their rated torque, the voltage and frequency (induction-motors) being maintained at their rated values. For d.c. motors, the torque may be expressed in terms of overload current.

Motors for duty type S9 shall be capable of withstanding momentarily an excess torque determined according to the duty specified.

Induction motors for specific applications

Motors intended for specific applications that require a high torque (for example for hoisting) shall be the subject of agreement between manufacturer and purchaser.

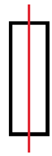
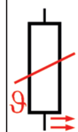
For cage-type induction motors specially designed to ensure a starting current less than 4.5 times the rated current, the excess torque can be below the figure of 60 % given above, but not less than 50 %.

In the case of special types of induction motors with special inherent starting properties, for example motors intended for use at variable frequency, the value of the excess torque shall be the subject of agreement between manufacturer and purchaser.

39.2 Protection provisions for the motor winding

There are various protection provisions for electric motors depending on the nature of the overloading. No single method can be described as offering “total protection”. This limitation is even more valid for geared motors – section 40 will make the reasons for this quite clear.

The table below summarises common types of overload and the features of different protecting equipment. Fuses have been included in the comparison to highlight the fact that they provide protection for the line only, not for the motor.

	Code	A	B	C	D	E
	Means of protection ➔ **➔ Type of overload**			 **2ph**	 	 **2ph** + 
1	Overcurrent $I \leq 2I_N$	□	■	■	■	■
2	Switching duty $Z \leq 30$ c/h	□	▼	▼	■	■
3	Switching duty $Z > 30$ c/h	□	□	□	■	■
4	Heavy starting duty $t_a > 6$ s	□	■	■	▼	■
5	Locked rotor at $i_A \leq 40$ A/mm²	▼	■	■	■	■
6	Locked rotor at $i_A > 40$ A/mm²	▼	■	■	▼	■
7	Single-phasing	□	▼	■	■	■
8	Voltage fluctuation $\Delta U > \pm 10$ %	□	■	■	■	■
9	Frequency fluctuation $\Delta f > \pm 5$ %	□	■	■	■	■
10	Ambient temperature $\vartheta_{amb} > 50$ °C	□	□	□	■	■
11	Poor ventilation	□	□	□	■	■
12	Inverter duty out of permissible frequency range	□	□	□	■	■

Explanation of the protection provision: □ – No protection
▼ – Partial protection
■ – Full protection

Explanation of the means of protection:

Code	Symbol	Explanation
A		Delayed action fuse Rating (1.6 ... 2.5) · I_N
B		Current-dependent thermally delayed overcurrent relay (Bimetal relay = Motor protective switch) Setting current $I_E = I_N$
C		Current-dependent thermally delayed overcurrent relay (Bimetal relay = Motor protective switch) with phase failure sensitivity, setting current $I_E = I_N$
D		TMS thermal motor protection (thermistor circuit-breaker) Response time $T_K < 6$ s
E	 + 	Current-dependent delayed thermal overcurrent relay (Bimetal relay = Motor protecting switch) with phase failure sensitivity Tripping characteristic TI Setting current I_E: 1.5 $I_N < I_E <$ 0.3 I_A as low as possible, but max. 0.3 I_A combined with TMS thermal motor protection (thermistor circuit-breaker) Response time $T_K < 6$ s

Explanation of the types of overload:

Code	Abb.	Explanation
1	I I_N	Actual overload current Rated current of the motor
2	Z	Switching cycles per hour; up to 30 c/h, no premature tripping is generally to be expected
3	Z	Number of switching cycles per hour; false tripping of the bimetal relay cannot be excluded at more than 30 c/h
4	t_a	Run-up time; if longer than 6 s, false tripping of the bimetal relay must be anticipated – possibly use a saturable current transformer
5, 6	i_A	Current density resulting from inrush current I_A
7	–	Particular danger for Δ-connected windings if single phasing sensitive devices are not provided
8	ΔU	Voltage fluctuation as a mains fluctuation; see also IEC 60034-1, subclause 12.3
9	Δf	Frequency fluctuation as a mains fluctuation; see also IEC 60034-1, subclause 12.3
10	ϑ_{amb}	Ambient temperature
11	–	e. g. by fouling of the air inlet paths
12	–	e. g. continuous duty at low frequencies

40 Gear loading

Damage or complaints about reduction gearing may be classified into the following groups:

- ☐ Noise
- ☐ Violent rupture
- ☐ Wear
- ☐ Heating.

High-grade helical gears can be expected to operate practically without wear if used as intended and lubricated correctly. Violent failures can only occur in the event of ***dynamic shock loading***. Objective measurable scales must be created for the analysis of noise; subjective assessment is not appropriate for the technical conditions.

40.1 Overload capacity of the gear unit

The resistance to failure of a responsibly designed gear unit that is being operated as intended is significantly higher than the breakaway torque of the motor assigned to it, unless particularly high reserves of motor performance have to be provided for very small initial outputs because of an expected difficulty (e. g. starting at very low temperatures). As a general rule, it is thus permissible to conclude that violent ruptures (shafts, keys, teeth) must be caused by dynamic shock torques far above the torques generated by the motor.

Full information on cause and effects can be found in the Danfoss-Bauer book "Protective measures for three-phase geared motors" and in special publication SD 32.. "Service factors". Just a few hints at this point:

- ☐ Avoid backlash in transmission elements (couplings, chains).
- ☐ Shock torques generated from mass effects (rotor flywheel energy) can be far greater than 10 times the rated torque.
- ☐ If stalling must be expected: Use slip clutches or at least highly resilient shaft couplings.

Figure 40.1.1
"Yielding" of a key below the end wheel of a gear unit during a static breakage test; torque when damaged around 26 ... 30 times the rated torque

Figure 40.1.2
Tooth breakage on the end wheel of a gear unit during a static breakage test; torque when sudden damage occurs is around 11.5 times the rated torque

40.2 Provisions for protecting the gear unit

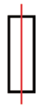
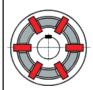
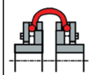
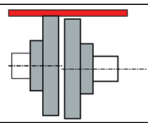
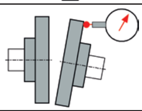
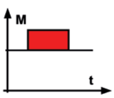
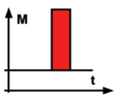
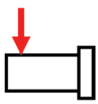
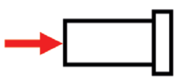
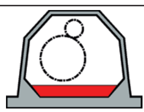
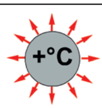
There is a fixed relationship between mechanical output and electrical power input for every type of motor under ***stationary*** operation. See this clear load characteristic, which is determined by measurement for every standard motor type and can be obtained from the manufacturer, enables the degree of loading to be ascertained with certainty on the basis of a simple operational measurement. Of course, this must also take into account the most unfavourable operating conditions. This simple procedure does not apply to ***dynamic*** processes because the flywheel energy of the rapidly-revolving motor rotor comes into effect during sudden stalling of the slow-running shaft and tries to maintain the existing conditions of movement by means of moments and forces which are greater, the more rapid the change in speed. These processes are independent of the speed-torque characteristics of the motor and require no energy from the mains supply and so cannot even be shown on extremely fast ***electric*** input plotters or other sophisticated electronic devices.
Among other things, the following may be concluded:

- ☐ Thermal overload protective devices reliably protect the windings but, for physical reasons, cannot protect mechanical components against abrupt overloading.
- ☐ Extreme forces may be generated from the “flywheel energy” of the rotating rotor of an electrical machine in the event of “locking”, this inevitably leads to mechanical components (shafts, keys, couplings) being damaged.
- ☐ Reliable overload protection for mechanical components cannot be provided “electrically”, but can only be achieved by placing a mechanical limitation on the torque peaks (e. g. through slip clutches, highly resilient transmission components or spring buffers).

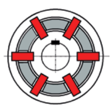
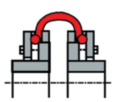
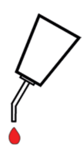
Further information on this topic can be found in the special publications
SD 24.. “Installation und Instandhaltung von Getriebemotoren [Installation and maintenance of geared motors]” and
SD 32.. “Service factors”.

The following table provides a schematic representation of a few common mechanical overload types and forms of protection.

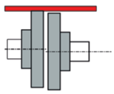
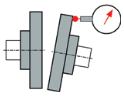
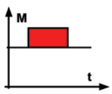
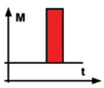
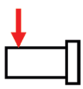
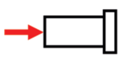
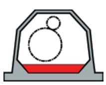
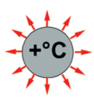
Explanation of the protection provision: ☐ – No protection
▼ – Partial protection
■ – Full protection

		A	B	C	D	E	F	G	H
	Element of protection ➔ Type of overload ➔								
1		□	□	□	▼	■	□	□	□
2		□	□	□	▼	■	□	□	□
3		□	▼	▼	□	□	□	▼	□
4		□	□	□	□	▼	■	□	□
5		□	□	□	□	▼	■	□	□
6		□	□	□	□	□	□	■	□
7		□	□	□	□	□	□	■	□
8		□	□	□	□	□	□	□	■
9		□	□	■	□	□	□	□	▼
10		□	□	□	□	□	□	□	■

Explanation of the means of protection:

Code letter	Symboll	Explanation
A		Delayed action fuse Rating (1.6 ... 2.5) · I_N
B		Current-dependent delayed thermal overcurrent relay (Bimetal relay = Motor protecting switch) Setting current $I_E = I_N$
C		TMS thermal motor protection (thermistor circuit-breaker); NAT (nominal actuation temperature) in accordance with section 14 Response time $T_K < 6$ s
D		Coupling with relatively high torsional stiffness, e. g. claw coupling, bolted coupling
E		Coupling with relatively high elastic torsion, e. g. with shaft tyres, springs
F		Slip clutch, centrifugal clutch, hydraulic clutch, shear pin, chain wheel with slip hub, shock absorber, resilient buffer; chain wheel with slip hub
G		Correct planning
H		Appropriate and timely lubrication

Explanation of the types of overload:

Code number	Symbol	Explanation
1		Shaft offset (misalignment)
2		Angular offset (misalignment)
3		Long-term overloading e. g. $M \geq 1.2 \cdot M_N$
4		Short-term torque shock, e. g. $M \geq 2 \cdot M_N$
5		Locking
6		Excessive radial force
7		Excessive axial force
8		Inadequate lubricant (quality or quantity)
9		Long-term excessive ambient temperature ≥ 30 °C
10		Ambient temperature too low when starting ≤ – 20 °C

41 Service factors

A designed-in or permissible overload capacity is expressed by “service factors”. Because international standards (outside the USA) have ***not stipulated*** the service factor for motors and gear units, it is essential to find out to what basis such a stipulated factor – which is often arbitrary and company-specific – refers. Comparing just the factors can result in the wrong decisions being made.

41.1 Service factors for motors

In the case of ***geared motors***, the “service factor” is always understood in Europe, and usually in North America, as a ***mechanical*** rating for the gear unit, i.e. in the sense of the definition given in section 41.2. However, North America also has a “service factor SF” for ***electric motors*** which is specified by some manufacturers on the rating plate of their motors and so can be incorrectly interpreted for geared motors.
There is, in fact, a clear definition in NEMA MG1-1.42:
“The Service Factor of a three-phase current motor is a factor which states how high the rated power may be raised under the conditions set out in MG1-14.37”.
It is stated in particular, that

- the increased output is available in continuous operation
- the winding temperature may be 10 K higher than the insulating material class (temperature class) assigned (NEMA MG1-12.43)
- efficiency and output factor alter
- service factor >1.0 may only be used in open-circuit air-cooled (ODP) motors (Table 12.4)
- totally enclosed fan cooled (TEFC) motors have a service factor of 1.0 (Table 13.3).

In spite of these specifications, “service factor SF” is one of the often misunderstood NEMA specifications. For example, it is often applied to ***standard enclosed*** (TEFC) motors, if these these are insulated with temperature class “F” material but are operated to class “B” (usual SF specification = 1.15). It is stipulated in NEMA MG1-10.40.1 that the current for the increased service factor need only be stated on the rating plate if it is greater than 1.0 – in standard IP54 motors (TEFC), that is to say, not as a rule.

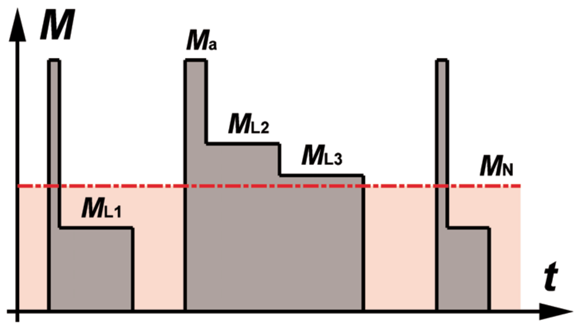
41.2 Service factors for gear units

Geared motors are constructed and put together according to a modular system which matches requirements, have a broad scope of application and are finely differentiated. Unlike the situation with vehicle transmissions or large gear units, future special usage cannot be taken into consideration at the development stage.

The most important characteristic quantity of this type of mass-produced gear unit is the ***rated torque*** that can be generated in continuous operation combined with an acceptable service life. In order to be able to compare the different applications, a fictitious torque must be formed and compared. The torques calculated from the individual load collective should be equivalent, i.e. in continuous operation they should lead to the same service life for corresponding gearbox size as loading with the actual torque. Similarly, code of practice VDI 2151, which has now been withdrawn, provided the following definition of the service factor:
"The service factor f_B is the number by which the nominal torque M_L of the driven machinery must be multiplied to obtain a fictitious torque *MN* that guarantees the same degree of certainty against operating damage for an action on the drive shaft which remains constant over any length of time as the actual torque acting on the drive shaft which changes over time.
The design of the gear unit is correct if its continuous-load capacity is equal to the fictitious torque M_N."

Figure 41.2
Definition of the service factor

M_a Acceleration torque
M_L Load torques 1, 2, 3
M_N Fictitious basic torque (rated torque) for equivalent continuous load with the same lifetime and safety



The formation of an equivalent rated torque from the load population M_a, M_{L1}, M_{L2}, M_{L3} taking account of the action times of each and the total running time requires considerable calculation effort. In the normal simplified method for geared motors, the torques (e. g. M_a, M_{L2} and M_{L3}) resulting from the nominal torque of the ***driven machinery*** are accounted for by a "shock classification".

What are the benefits of using service factors to the designers and users of geared motors?

- ☐ A standard drive which can be manufactured more cheaply can be adapted to a specific drive task.
- ☐ The driven machinery's torque shocks resulting from operation and additional shock loads due to unsuitable power transmission components are assessed and either reduced by improving the design or taken into account in the dimensioning of the gear unit.
- ☐ Transmission damage is avoided to a large extent.

For further information, see Danfoss-Bauer special publication SD 3200 E.

IX SPEED ADJUSTMENT

In drive technology there is an increasing demand for steplessly adjustable speed. There are numerous reasons for this and the list below contains just a few:

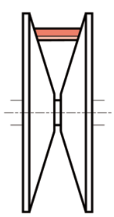
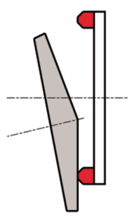
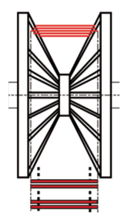
- ☐ Adaptation to changing products
- ☐ Improvement of methods
- ☐ Energy conservation
- ☐ Operational safety
- ☐ Protection of the environment
- ☐ Low maintenance.

Detailed information on this subject can be found in Danfoss-Bauer special publication SD 29 .. “Umrichter-Motoren” [Inverter-fed motors].

42 Mechanical adjustable-speed gear units

Mechanical adjustable-speed gear units all but dominated the variable-speed drive market until the inverter-fed three-phase motor provided an alternative in terms of technology and price from roughly the mid 80s onwards. This concept was reluctantly accepted first but has since become superior. Four mechanical variants widely used in practice have been selected from the vast array of different types of design. Mechanical speed adjustment solutions are increasingly being replaced by inverter-fed motors but still have a small market share where speed adjustment is not a frequent requirement and where staff with appropriate qualifications are not available to set up and maintain electronic components.
The level of efficiency is not usually the decisive factor in the selection of the drive principle; the following considerations often speak in favour of the electrical solution:

- ☐ Adjustment range
- ☐ Controllability
- ☐ Wear
- ☐ Noise
- ☐ Speed preselection at rest.

				
System	Wide-angle V-belts	Friction disc	Rolling elements	Multiple-disc chains
Adjustment range *R*	3 ... 9	5 ... 10	5 ... 10	6 ... 10

43 Pole changing for two fixed speeds

Three-phase motors with pole-changing winding are often used in drive system applications where the requirements are not very high (for example, in terms of the ability to adjust the speed, positioning tolerance, soft switching). Speed ratios of 1 : 3, 1 : 4, 1 : 6 or 1 : 10 are often required for positioning. A ***single*** winding in ***Dahlander connection*** is all that is required for a speed ratio of 1 : 2. All other speed ratios need two separate stator windings, which of course involves lengthier manufacturing processes (**Figure 43.0.1**) and consequently higher costs (**Figure 43.0.2**). Nevertheless, in the case of low speed ratios, they are still less expensive than motors with stepless speed control (such as DC. motors or inverter-fed motors) (in the diagram they are shown as a function of an upper speed of around 100 r/min and the same maximum power).

Figure 43.0.1
Manual formation of two separate windings on a pole-changing motor

The 20-pole winding is fully installed in the slot ground

The 2-pole winding is partly installed in the slot opening

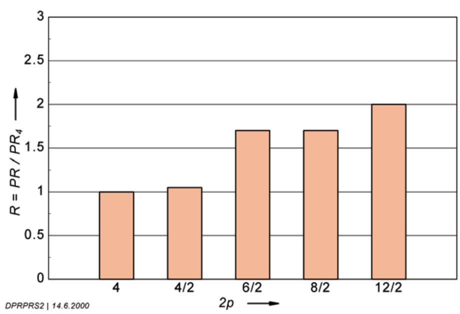


Figure 43.0.2
Guide values for the costs of pole-changing geared motors with speed ratios of 1 : 2 (4/2-pole), 1 : 3 (6/2-pole), 1 : 4 (8/2-pole), 1 : 6 (12/2-pole) and 1 : 10 (20/2) compared to a geared motor with a fixed speed (4-pole)

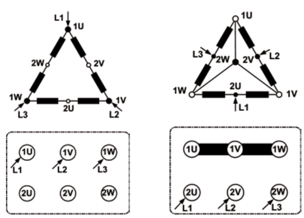
43.1 1 : 2 speed ratio (Dahlander connection)

Pole-changing at a ratio of 1 : 2 is quite frequently used because the direction of the current in the part-phases of the winding can be altered simply by switching the connections on the terminals to produce two rotating field speeds in the ratio 1 : 2 (**Figure: 43.1.2**). This type of connection is termed the “Dahlander connection” after its discoverer. The entire slot lining is active at both speeds, unlike two separate windings (section 43.2) – resulting in relatively high model utilisation. Although this benefit is also given by special connections, these require either a very high number of terminals or a very complicated multi-stepped winding. Dahlander connection is a relatively cheap way to achieve speed-stepping, even if this is only in the ratio of 1 : 2, thus making it unsuitable for applications where demands are higher. Whilst the maximum permissible thermal output is given in the catalogues for three-phase standard motors (without gear units), this may not always be the most cost-effective solution for geared motors. If one sets the torque at high speed at 100 %, the permissible torque (from a thermal load point of view) at low speed will be approximately 150 % (1/0.65 = 1.5) for a 4/2-pole motor. The gear unit must be rated for this 150 % torque. With slow-running drives, it may be assumed that the torque requirement is used primarily to overcome friction or a hoisting load; in other words, it is approximately the same for both (linear) speeds. The potential torque at the low speed (150 %) is far too high. The gear unit could be rated for 100 % torque and thus be more cost-effective. Danfoss Bauer therefore offers a more cost-effective gradation for pole-changing motors, as shown in **Table 43.1.1**:

Pole-changing	Relative torques		Relative outputs	
Δ/YY	Low speed	High speed	Low speed	High speed
4/2 8/4	100 % 100 %	≈ 100 % ≈ 100 %	100 % 100 %	≈ 200 % ≈ 200 %

Table 43.1.1 Gradation of torque and power rating for pole-changing three-phase geared motors in Dahlander connection with more cost-effective gear utilisation for a constant torque

Figure 43.1.2
Terminal connections on the Dahlander connection for two speeds at a ratio of 1 : 2



43.2 Other speed ratios (dual winding)

Two windings inserted separately in a stator are usually used for two speeds with a ratio differing from 1 : 2. The effort associated with the winding technology required, comprising insertion work, wiring and insulation (coil from coil and winding from winding), is large. Machine winding is usually not possible; the proportion of manual labour (i.e. the labour component of the costs) is relatively high.

43.2.1 Terminal connection

The mains connections may be connected to the two windings if desired on motors with two separate windings and various pole numbers (**Figure 43.2.1**). The windings are normally connected inside the motor in a star configuration and led to the terminals with three ends. Additional delta/star (Δ/Y) tap changing is certainly possible but is limited to special cases as 12 terminals and usually an enlarged terminal box are required.

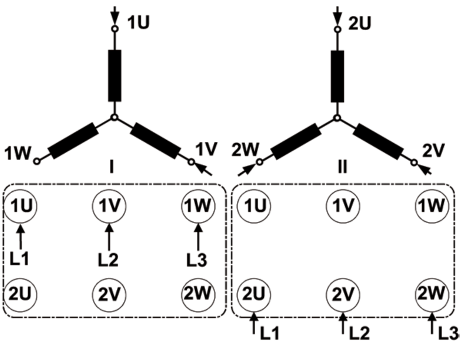


Figure 43.2.1
Circuit diagram for two separate windings, two speeds, I and II

43.2.2 Possible speed ratios

There are physical and manufacturing limits on the possible number of poles. The lowest number of poles is 2 (3000 r/min at 50 Hz). The highest number of poles possible at a justifiable cost depends on the frame size of the motor. The speed ratios given in Figure 43.2.2 are standard for positioning motors.

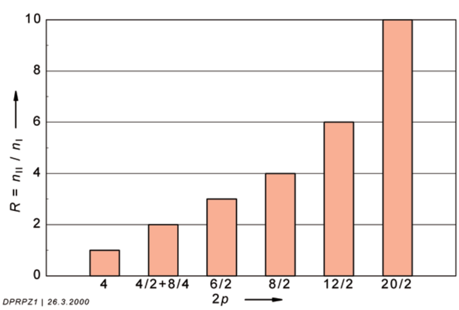


Figure 43.2.2
Speed ratio *R* of pole-changing positioning motors with two speeds

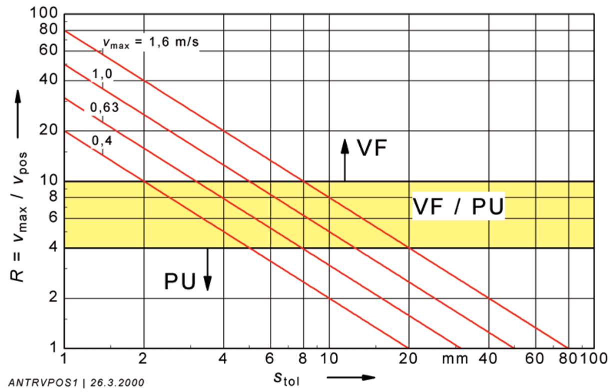
43.3 Pole-changing limits

The higher the running speed and the lower the permissible stopping tolerance, the greater the speed ratio required. The Danfoss-Bauer book “Starting, braking, positioning with three-phase cage induction motors” quotes values obtained from experience, but which are no substitute for recalculations in individual cases. **Fig 43.3.1** shows the limits of the drive systems:

- ☐ Speed ratios $R \leq 4$ allow the conventional pole-changing PU solution to be used.
- ☐ Speed ratios $R > 10$ generally necessitate the variable frequency VF solution.
- ☐ In the $4 < R \leq 10$ range, the two solutions compete with VF having the advantage in terms of technology and PU the advantage in terms of cost.

Figure 43.3.1
Limits of use in relation to the expected stopping tolerance s_{tol} and to the running speed v_{max}

PU
Pole-changing
VF
Variable frequency



In addition to technical considerations, cost is also decisive in the decision-making process, but not only in the transitional range. The development of a compact solution that can be integrated into the motor terminal box (**Figure 43.3.3**) makes the selection of inverter feed easier, particularly in the difficult power range up to 7,5 kW, as shown in **Figure 43.3.2**. This price comparison is based on the following assumptions which may need to be modified to suit the particular case but should be borne in mind as far as switchgear and control units are concerned:

- ☐ Speed ratio 1 : 6
- ☐ Cyclic duration factor (ED) 60 % with VF and 25/75 % with PU
- ☐ Thermal motor protection (TMS) by means of thermistors (a circuit-breaker is supplied as standard with the inverter)
- ☐ Contactors for pole-changing (not required with inverters)
- ☐ Wiring and installation costs have not been taken into account (higher with PU than with VF).

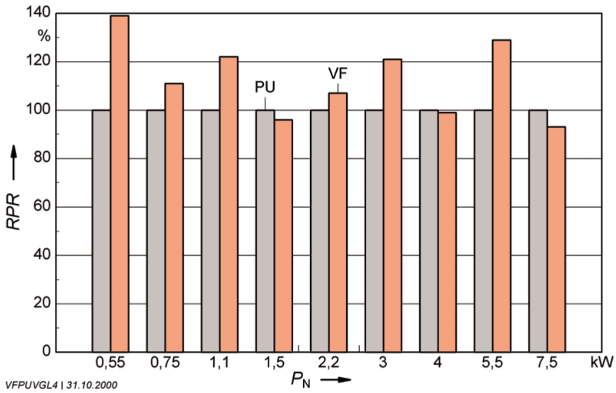


Figure 43.3.2
Guide values for the relative price *RPR* of drive solutions with pole-changing (PU) and integrated inverter (VF)

See the text for marginal conditions

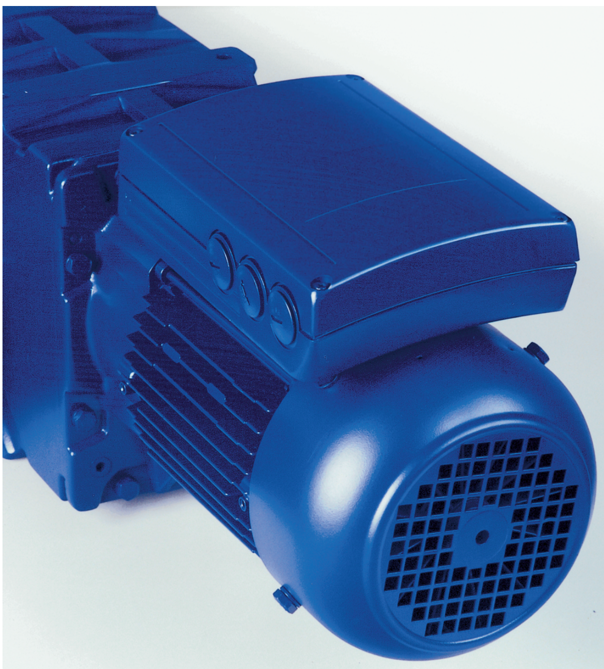


Figure 43.3.3
“Eta-K” – Three-phase geared motor with built-on frequency converter to form a compact drive
Rated outputs P_N to 7.5 kW

Integrated protective devices against overload, overcurrent, phase failure, overvoltage and undervoltage.

Thermal monitoring for the motor and inverter.
Connected by a plug to the motor unit
Degree of protection IP65.

44 Inverter-fed motors

Any kind of stepless speed variation demands additional expenditure of technique and cost. The drive system component to be installed “on site” is generally modified and thus becomes the “weak point” (**Figure 44**). ***Inverter-fed motors are different in this aspect***:
Apart from minor modifications of the winding design, frequency-controlled three-phase motors are the same as standard motors. If fully protected from dust and water (as in degree of protection IP65) the motor may be installed “right at the point of application”, even under the most difficult environmental conditions. All complicated and sensitive means necessary for stepless speed adjustment are integrated in the frequency inverter and can be installed in a non-hazardous, clean and easily accessible room or in the control cabinet. The power source and the motor are linked by an “intermediate circuit”.
There are very few speed control systems that offer such complete separation of complicated control elements from simple drive elements as the frequency-controlled three-phase induction motor.
Inverter-fed motors are therefore most suitable for difficult or inaccessible locations.

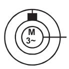
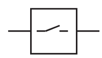
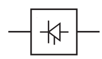
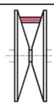
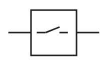
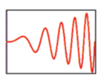
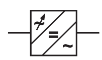
Difficult area			**Non-hazardous area**
e. g. Water, corrosion, dust, explosion		**Special features**	**Electrical equipment**
DNM		Sliprings / collector brushes	
GM		Collector brushes	
VGM		Belt / slip / electrostatics wear	
UM		Variable frequency 	

Figure 44 Comparison of variable speed drive systems
DNM – Three-phase shunt wound motor
GM – DC motor
VGM – Adjustable geared motor with wide-angle V-belt gear unit
UM – Inverter-fed motor

44.1 Speed and slip

The principle for speed variation is simple:
The synchronous speed of a three-phase cage motor depends is directly related to

$$n_{sy} = \frac{60 \cdot f}{p}$$

n_{sy} – Synchronous speed in r/min
f – Frequency in Hz
p – Number of motor pole pairs.

The synchronous speed therefore depends directly on the supply frequency. In order to create torque, the induction motor rotor must remain at the slip speed in relation to the synchronous rotating field:

$$n_N = n_{sy} - n_{Sl}$$

n_{Sl} – Slip speed in r/min
n_{sy} – Synchronous speed in r/min
n_N – Asynchronous speed at rated torque in r/min

The slip is calculated from this, in %

$$s = \frac{(n_{sy} - n_N) \cdot 100}{n_{sy}} = \frac{n_{Sl} \cdot 100}{n_{sy}}$$

The rotor slip frequency in Hz

$$f_{Sl} = \frac{n_{Sl} \cdot p}{60}$$

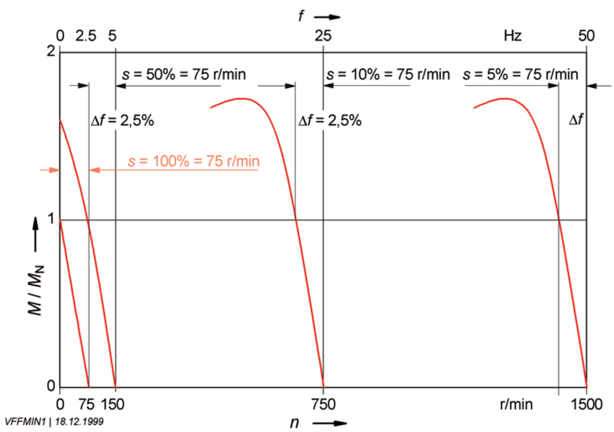


Figure 44.1
Torque-speed characteristic of an induction motor at 50/25/2.5 Hz

Relevant slip speed 75 r/min,
Relevant slip frequency 2.5 Hz

The diagram clearly shows that a ***minimum frequency*** (for example 2.5 Hz) is necessary in order to start up the drive from a standstill at the relevant rated torque. With the correct thermal design, operation at speeds of a little over 0 is possible. This representation is also true in the case of conventional U/f control. With modern flux vector control, the inverter itself ensures optimal adaptation of the U/f characteristic graph. The speed range is therefore ***largely greater than the frequency range*** calculated in the usual way (in example 50/2.5 = 20).

44.2 Voltage/frequency ratio (U/f characteristic graph)

In the case of induction motors, the torque is proportional to the square of the magnetic flux: $M \sim \Phi^2$
Voltage and frequency must therefore be altered such that the magnetic flux remains constant (**Figure 44.2.1**)

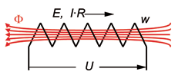
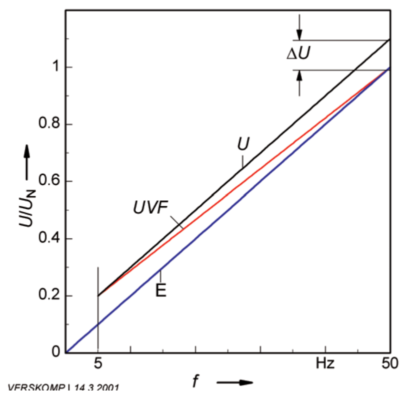
	$U = E + R \cdot I$ $E = 4{,}44 \cdot f \cdot w \cdot \Phi \cdot \xi_w$ $\Phi \sim \frac{E}{f} = \frac{U - R \cdot I}{f}$ $\Phi \sim \frac{U}{f}$	M – Torque U – Voltage f – Frequency I – Current	E – Induced voltage Φ – Magnetic flux w – Number of turns per unit length ξ_w – Winding factor R – Ohmic resistance

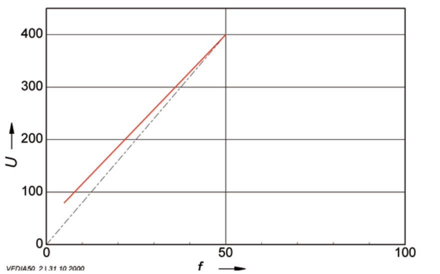
Figure 44.2.1 Faraday‘s law and relationship between voltage, frequency and flux

The (induced) voltage must be altered in theoretically direct proportion to the frequency. The ohmic voltage drop in the rated voltage range may be ignored, i.e. it is permissible to use $U \approx E$. Since the value $\Delta U = I \cdot R$ remains the same for all frequencies, the ohmic voltage drop at low frequencies has a very marked percentage effect and must therefore be compensated for.
This results in the basic voltage/frequency characteristic graph in accordance with **Figure 44.2.2**. Optimum motor magnetisation is achieved by the frequency inverter which monitors the machine constants (primary resistance and inductance). The frequency inverter uses this data to calculate the ***optimal output voltage***. Since the frequency inverter is constantly measuring the load current, it can regulate the output voltage in accordance with the load. The motor voltage is thus adapted to the motor type and the load is then changed.

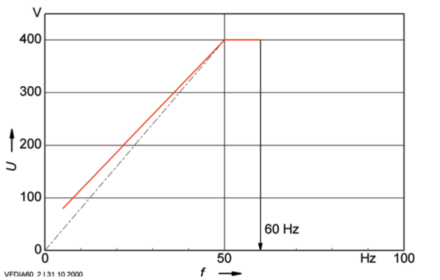
Figure 44.2.2
Basic voltage/frequency characteristic graph
The voltage drop ΔU is only fully compensated for in the lower frequency range.



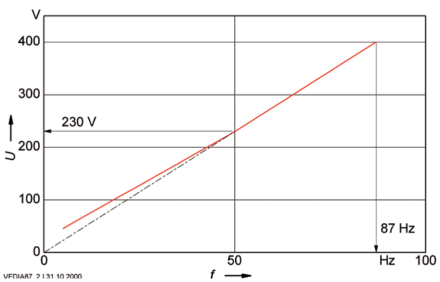
44.3 Examples of *U*/*f* characteristic graphs



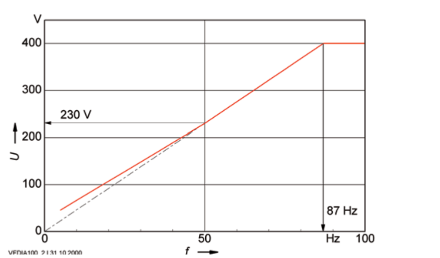
a)
Maximum voltage (e. g. 400 V) at a supply frequency of 50 Hz
No field weakening
Speed range e. g. 1:5, 1:10
Motor winding for 400 V, 50 Hz



b)
Maximum voltage (e. g. 400 V) at a supply frequency of 50 Hz
Field weakening 1:1.2; 50 ... 60 Hz
Speed range e. g. 1:6, 1:12
Motor winding for 400 V, 50 Hz



c)
Maximum voltage (e. g. 400 V) at a frequency of 87 Hz
No field weakening
Speed range e. g. 1:10, 1:20
Motor winding for 230 V Δ, 50 Hz
(= 400 V Y)



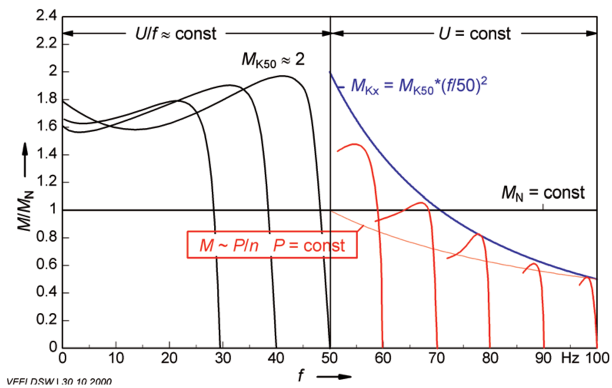
d)
Maximum voltage (e.g. 400 V) at a frequency of 87 Hz
Field weakening 1:1,15; 87 ... 100 Hz
Speed range e.g. 1:10, 1:20
Motor design for 230 V Δ, 50 Hz
(= 400 V Y)

Figure 44.3 Examples of standard, proven *U*/*f* characteristic graphs

44.4 Field weakening

The voltage limit and the continuous current have a significant effect on the power semiconductor costs. Inverters with a rated voltage of 220 (230) V are therefore particularly economical for small motor outputs. With average and larger outputs, a semiconductor with as high a rated voltage as possible (e. g. 400 V) would be selected, so that the rated current is as low as possible. This rated voltage is generally assigned to the upper limit frequency (e. g. 400 V/87 Hz); the *U/f* characteristic graph is, for example, as per c) in Figure 44.3.
If the rated voltage of the inverter is assigned to the supply frequency (i.e. 400 V/50 Hz), smaller rated currents are produced and, if necessary, more economical inverter and current sizes. However, the motor functions in the 50 – 87 Hz range as per characteristic graph b) in diagram 44.3 with the “field weakening”, i.e. the magnetic flux does reduce along with the frequency in the 50 – 87 Hz range in accordance with section 44.2 – the breakdown torque is reduced with the square law. At the upper limit frequency of 87 Hz, the breakdown torque is as low as approximately 1/3 (**Figure 44.4**). This *U/f* characteristic graph with a speed range in the field weakening range of 87/50 = 1.73 is only recommended for drives with correspondingly lowered torque requirements.
For the most common drive types in handling technology with a largely constant torque requirement over the entire speed range, the general rule is:
Maximum field weakening speed range approximately 1:1,2, e. g. 50 – 60 Hz or 87 – 100 Hz.

Figure 44.4
Torque characteristic graphs at *U/f* = const
(graph as per Figure 44.3a)
and at field weakening
U = const
(graph as per Figure 44.3b)



Up to 50 Hz, there is an almost constant flux, i.e. a high breakdown torque (e. g. M_K/M_N = 2 at 50 Hz). With a field weakening speed range of > 50 ... 100 Hz, the breakdown torque M_{Kx} reduces proportionally to the square of the frequency. Taking into account the overload reserve, a constant rated torque M_N can only be achieved up to 60 Hz. If only constant power P is required in the field weakening speed range, the reduced torque of up to around 80 Hz can be employed as rated torque.

The limits shown above for the field weakening speed range are derived from these conditions. This representation makes it clear that in individual cases, the permissible speed range with field weakening depends on

- the relative breakdown torque M_K/M_N which is provided by the standard motor at 50 Hz as a reserve;
- the minimum overload capacity required in the field weakening speed range, which can be high when there is a real danger of overloading and with heavy starting, and which can be correspondingly low with lighter drives.

44.5 Influence of the speed range on the torque reduction

The influence of ***harmonics*** is negligible provided a PWM inverter is used, and is relatively low (10 ... 15 %) with older systems.
As shown by **Figure 44.5**, however, the extended adjustment range is most important for the actual “constant torque” available in a speed range: Lines 5 and 20 indicate that only 65 – 70 % of the original nominal torque is available if – as is often the case – 87 Hz has been set as the upper frequency limit. For this reason, the speed range should be kept as small as possible.

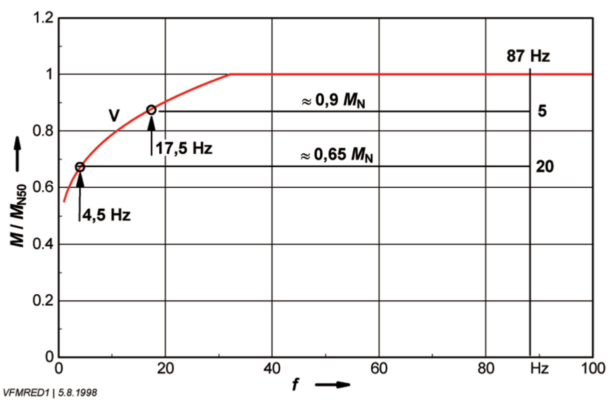


Figure 44.5
Necessary torque reduction in inverter duty $f = 3 \dots 87$ Hz

V – due to reduced integral fan cooling in case of S1
5 – due to a “constant torque” in the 1 : 5 speed range
20 – due to a “constant torque” in the 1 : 20 speed range.

Detailed descriptions of the questions raised briefly, and many other points can be found in the

- Danfoss book “Facts worth knowing about frequency inverters”
- Danfoss-Bauer special publication SD 29.. “Umrichter-Motoren [inverter-fed motors]”.

X SPECIAL MOTORS

45 Reluctance motors

The speed characteristic of the induction motor with a slip of up to around 10 %, as described in Section 8, is not acceptable for some applications. The very highest requirements for ***speed constancy*** can be met by reluctance motors, which can be produced by modifying the components of an induction motor. A varying magnetic resistance (reluctance) around the circumference of the rotor can be achieved by making cutouts in the rotor in the form of pronounced poles (**Figure 45.1**). The magnetic lines of the rotating field tend to spread into magnetically conductive material and thereby develop a synchronous rotating driving force which is kept within limits by the ***synchronous pull-out torque*** M_{Ksy}.
If the motor "falls out of step", it continues to run as an induction motor with relatively high slip, until the ***pull-in torque*** M_{sy} is sufficient to overcome the load torque (**Figure 45.2**). Whilst the ***pull-out torque*** is determined by the design of the motor, the pull-in torque changes with the total amount of rotating mass that is to be driven, i.e. the factor of inertia *FI*. If *FI* is greater than around 1.5 the manufacturer must be consulted. Starting is carried out with the aid of the remaining cage winding, with starting current and breakaway torque being considerably greater than on an induction motor of the same rated power. The simple principle and the robust construction that is comparable with the induction motor ensure that the reluctance motor offers some advantages over synchronous motors with excitation windings in the power range up to around 10 kW. The rated power of a reluctance motor is a maximum of 50 % of the unit rating of an induction motor. Pole-changing for two speeds is not possible. When suitably fitted, the reluctance motors are suitable for frequency control (inverter duty).

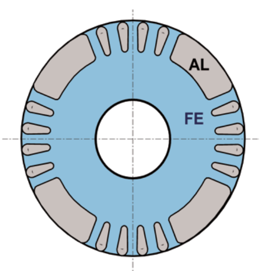


Figure 45.1
Rotor of a reluctance motor with pronounced poles for low magnetic resistance (reluctance) in iron (Fe) and with high magnetic resistance in die-cast aluminium (Al)

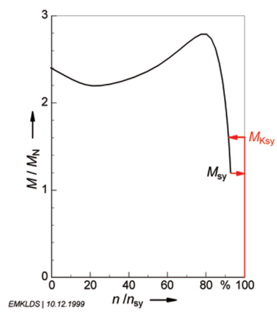


Figure 45.2
Speed-torque characteristic graph of a reluctance motor with synchronous pull-out torque M_{Ksy} and pull-in torque M_{sy}

46 Crane drives with slip rotors

Because of their swinging loads suspended from cables, crane and trolley travelling gears require drives that have very ***smooth starting and braking performance*** (**Figure 46.1**). A detailed presentation can be found in the Danfoss-Bauer book "Starting, braking, positioning with three-phase cage induction motors".

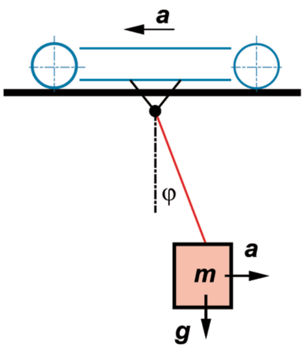


Figure 46.1
Oscillation of a load suspended from a cable

$$a \leq \tan\varphi \cdot g$$

a – Acceleration in m/s²
φ – Angle of displacement (experience provides a maximum value of 3°, therefore $a \leq 0.5$ m/s²)
g – Acceleration due to gravity (9.81 m/s²)

Slipring motors used to be applied for such drives. Starting slipring motors by means of rotor starters – which are not considered in detail in this discussion – has some definite benefits (**Figure 46.2**):

- ☐ The speed can be divided into several steps. A short dwell time at part speed allows the load time to "get used" to the speed and stop swinging, for example.
- ☐ The triangular areas with constantly reducing torque provide a soft speed transition comparable with "cosine smoothing".
- ☐ The thermal losses occur primarily in the starting resistor, i.e. outside the machine from where they can be easily conducted away.

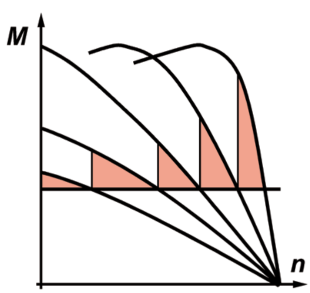
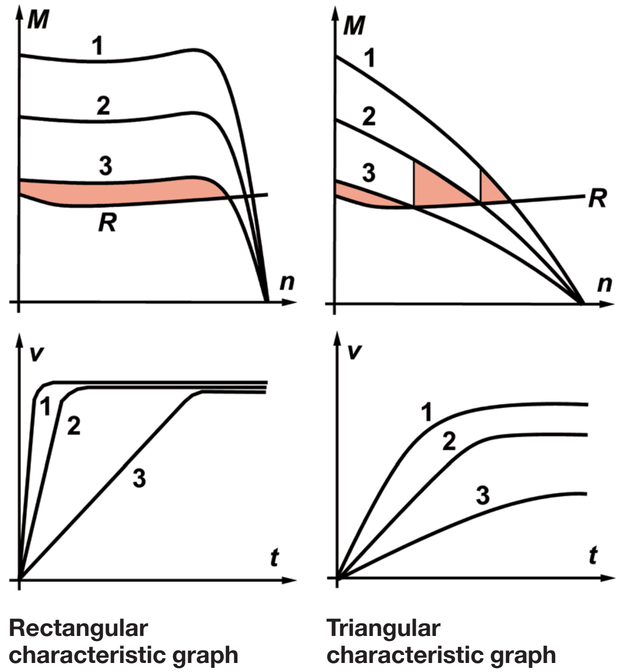


Figure 46.2
Speed-torque characteristic graph of a slipring motor when started in five speed stages

Induction motors with ***special cage rotors*** combine some of these benefits with the simple principle of the cage rotor. This is clearly indicated by the schematic diagrams shown in **Figure 46.3**.

Figure 46.3
Comparison of rectangular and triangular characteristic graphs for torque steps (1, 2, 3) down to slightly above the frictional torque R showing the effect on the *v*/*t* graph



The oscillogram in **Figure 46.4** shows the soft transition to the final speed. The "triangular" characteristics are achieved by using a special slot and/or by using high-resistance material in the pressure diecast rotor. The ***slewing*** and ***travelling gear*** of many small and medium-sized cranes have been equipped with special drives (termed DL by Danfoss Bauer), the outward appearance of which does not differ from that of normal AC cage induction motors. Because it is not possible to connect to the rotor circuit, steps 1, 2 and 3, as shown in Figure 46.3, are achieved using "reinforced star-delta (Y-Δ) starting".

Figure 46.4
Comparison of current *I*, rotor speed *n* and linear speed *v* over the acceleration period *t* for a conventional drive (D) and a special crane drive (DL)

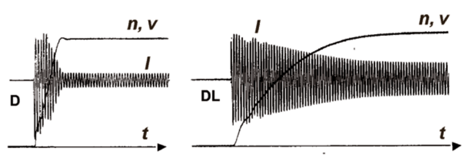


Figure 46.5
Special type DL AC induction motors
on the travelling gear of a gantry crane

47 Roller-table drive

The drives for roller tables in rolling mills must be selected in accordance with particular features which differ considerably from those in the design of other drives. While most drives are rated according to the continuous output required, opposing field braking, start-ups and idle periods follow quickly on from one another in the case of the roller-table motor. Actual transport effort is relatively slight. In addition to these special requirements, it is above all the mechanical stresses, which can often be difficult and the sometimes quite significant temperature influences which make careful design of roller-table drives necessary. There is a comprehensive guide in Danfoss-Bauer Special Publication SD 8.. “Selection of roller-table drives”

47.1 Examples of applications

Roller tables are used for the transport of cold or hot material in the form of blocks, rods, pipes or slabs in rolling mills or in the metal processing industry.

- ☐ ***Working roller tables*** either side of the roll stand are intended to brake the generally red-hot material as quickly as possible and then to accelerate it towards the roll stand (**Figure 47.1.1**).
- ☐ ***Feeding roller tables*** transport the blocks or slabs from the furnace to the working roller table.
- ☐ ***Delivery roller tables*** take the product which has been rolled out into billets or bars and transport it for further processing (shear, straightening press, etc.).
- ☐ ***Cooling bank roller tables*** have a slow, oscillating movement which permits uniform cooling of the material (**Figure 47.1.2**).

There are different considerations in the selection and design of roller table drives depending on the application.

Figure 47.1.1
Shaft-mounted roller-table geared motor on a working roller table

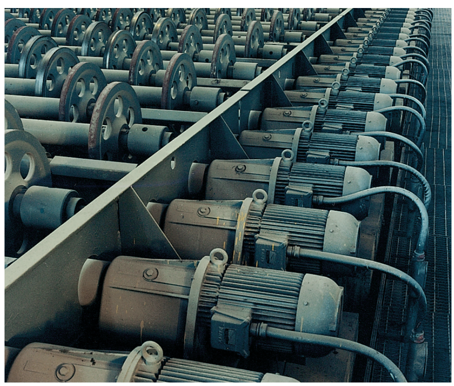


Figure 47.1.2
6 Hz oscillating table on a cooling bank for heavy plates

47.2 Rating data

The principal task of the drives on working roller tables is to ***brake and accelerate*** the material being transported. Relatively little power is required in the intermediate transport phase. It has therefore been usual, since the introduction of this type of drive, but at least for more than 50 years, to dimension and classify roller table drives not by their kW-output, but by their ***starting torque***. Unfortunately, this way of describing motors, which is to be preferred from the point of view of motor technology, has not become common practice for other, comparable, types of drive (e. g. crane travelling drives).

47.2.1 Starting torque

The starting torque of a three-phase induction motor designates, according to **Figure 47.2.1** an important point on the torque characteristic graph, but does not give any comprehensive information regarding its run-up behaviour. If the mean run-up torque is taken as a good approximation of what determines the run-up time, the theoretical difference between the ***"rectangular characteristic graph"*** and the ***"triangular characteristic graph"*** is 1 : 2, in practice approximately 1 : 1.5 in the run-up time. This can translate into a significant time benefit for rapid pass sequences.

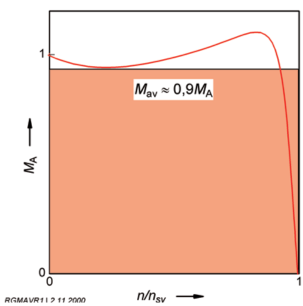


Figure 47.2.1.1
Mean run-up torque M_{av} on a roller table motor with a "rectangular characteristic graph"

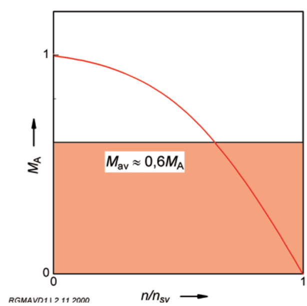


Figure 47.2.1.2
Mean run-up torque M_{av} on a roller table motor with a "triangular characteristic graph"

47.2.2 Synchronous speed

Since roller table drives are not characterised by nominal output = rated power, the load speed, otherwise usual for induction motors cannot be specified. Instead, the synchronous speed is given on the rating plate. The actual speed is only a little below the synchronous speed in the light-load period between acceleration and braking.

47.2.3 Acceleration value (B value)

The "acceleration value" (B-value), which has not been standardised, has become usual as the metric for the thermal working capacity of roller-table motors. It is a simple metric for describing how often and against which mass moments of inertia it is permissible to accelerate per hour within the thermal limits of the motor winding.

47.2.3.1 Definition of the acceleration value

The acceleration value as a metric for the acceleration work to be applied per hour is determined as follows:

$$B = \Sigma J_1 \cdot Z$$

B – Acceleration value (B-value) in kgm^2/h
J_1 – Total mass moment of inertia ($m \cdot r^2$) in kgm^2 related to the rotor speed n_1, i.e.

$$\Sigma J_1 = \frac{J_{ext}}{i^2} + J_{rot}$$

J_{ext} – External mass moment of inertia in kgm^2
J_{rot} – Rotor mass moment of inertia in kgm^2
i – Gear reduction ratio
Z – Number of switch on cycles per hour in c/h.

The unit of kgm^2/h, which is not usual in physics, may be understood if the mass moment of inertia is taken to be the calculated substitute for the run-up or deceleration time:

$$t_a = \frac{\Sigma J \cdot n}{9{,}55 \cdot M_a}$$

n – Speed in r/min
M_a – Acceleration torque in Nm.

Taking $t_a \sim \Sigma J$, $B \sim t_a \cdot Z$:

The B-value thus represents the time in an hour in which the drive is operating in high current conditions under acceleration and deceleration.

Applying the factor of inertia, which is frequently used and has been standardised

$$FI = \frac{J_{ext1} + J_{rot}}{J_{rot}} = \frac{\frac{J_{ext}}{i^2} + J_{rot}}{J_{rot}}$$

the acceleration value becomes

$$B = FI \cdot J_{rot} \cdot Z$$

When calculating the total mass moment of inertia ΣJ_1 any idle rollers and the associated block component must additionally be applied.

47.2.3.2 Determination of the acceleration value

The rated acceleration values B_N listed have generally been determined by testing (**Figure 47.2.3.2**). To do this, the motors are initially run under no load, and then with varying frequencies of reversing until the equilibrium temperature is reached.

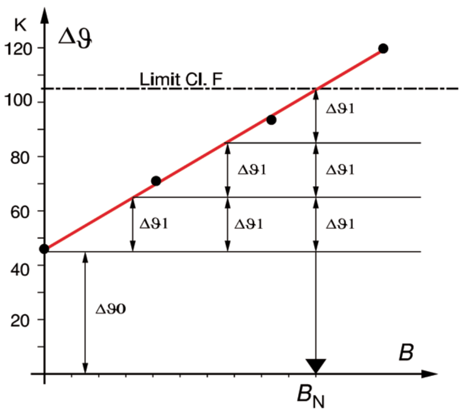


Figure 47.2.3.2
Determination of the rated acceleration value B_N taking into consideration the temperature rise limit for temperature class F

• – Test points

The copper temperature rises $\Delta\vartheta$ are plotted against the B-value. As Figure 47.2.3.2 shows, these lie on a straight line. An additional temperature rise $\Delta\vartheta_1$, directly proportional to the B value, is added to a base value for the no-load (magnetisation) temperature rise ϑ_0 (45 K in the example). The intersection of this straight line with the temperature rise limit for temperature class F (Limit Cl. F) then gives the rated acceleration value B_N.

47.2.3.3 Exploiting the acceleration value

The rated B value of a motor can be exploited within the usual practical limits, either through high switching frequency with a low mass moment of inertia or through low switching frequency with a large mass moment of inertia. The temperature rise is identical in the two load cases. However, the mechanical shock loading on the power transmission components will increase with the mass moment of inertia.

Where the rated B value of a specific roller table motor is exploited to the full, the permissible external mass moment of inertia for coupling, roller and block may be calculated for a given switching frequency Z:

$$J_{ext} = \left(\frac{B}{Z} - J_{rot} \right) \cdot i^2$$

Figure 47.2.3.3 shows that, with increasing switching frequency, an increasing proportion of the thermal working capacity is consumed by the motor rotor.

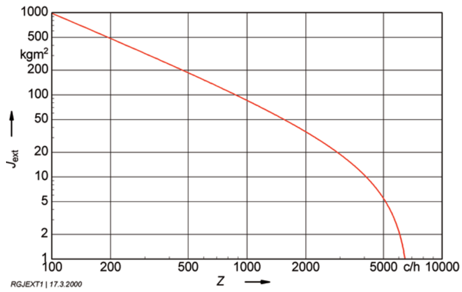


Figure 47.2.3.3
Permissible external mass moment of inertia J_{ext} at different switching frequencies Z, related to the output shaft of an 8-pole roller table geared motor with a rated torque of 1250 Nm, a speed of 75 r/min and a B value of 1000 kgm^2/h

47.3 Torque requirement

The torque required may be determined by the following method:

47.3.1 Minimum torque

The torque developed by the drive should be at least as great, for most transport tasks, that the roller can turn from rest under the hot rolling material which has been stalled for any reason, i.e. is blocked. The risk of local overheating and deformation of the roller is prevented in this way. Should this torque be required frequently or for long periods because of the operating duty, the drive must be dimensioned accordingly from the point of view of thermal protection. This requires particular agreement. The situation is illustrated diagrammatically in **Figure 47.3.1**.

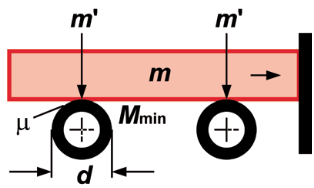


Figure 47.3.1
Illustration of the principle of the determination of minimum torque

$$M_{min} = \mu \cdot m' \cdot g \cdot \frac{d}{2}$$

M_{min} – Minimum torque in Nm
μ – Coefficient of friction
m' – Mass (weight) per roller in kg
g – Acceleration due to gravity (9.81 m/s²)
d – Roller diameter in m

47.3.2 Maximum torque

The torque developed by the drive is distributed on acceleration in accordance with the mass components onto motor rotor, coupling, roller and material being conveyed.

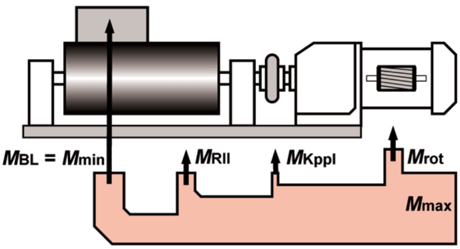


Figure 47.3.2.1
Distribution of the torque developed by the motor M_{max} to the rotor, coupling, roller and block

The acceleration transferable from the roll onto the material being rolled is limited to a maximum value in the case of a frictional force, as the following is true for the force applied to the material to be conveyed

$$F_{max} = \mu \cdot m \cdot g$$

Since, on the other hand

$$F_{max} = a_{max} \cdot m$$

is true for the ***maximum transferable acceleration (deceleration)***:

$$a_{max} = \mu \cdot g$$

If this limit value is exceeded, the roller and rotor are accelerated more rapidly than the material to be moved: Since the coefficient of sliding friction decreases significantly with increasing relative speed between roller and material, particularly in the case of hot semi-solid material, the acceleration (or braking) of the material is reduced to an unacceptable extent.

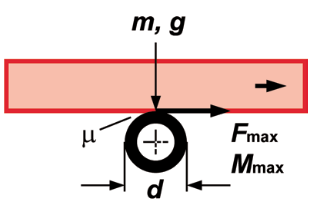


Figure 47.3.2.2
Illustration of the principle of the determination of maximum torque

The following is true for the maximum torque transmissible by friction from the roller to the material to be transported:

$$M_{max} = \frac{2 \cdot g \cdot \mu \cdot J}{d} \approx \frac{20 \cdot \mu \cdot J}{d}$$

M_{max} – Maximum torque in Nm
μ – Coefficient of friction
J – Mass moment of inertia of all moving parts in kgm²
g – Acceleration due to gravity (9.81 m/s²)
d – Roller diameter in m

47.3.2 Maximum torque

The following is applied for the torque M actually to be selected:
$M_{\mathbf{min}} \leq M \leq M_{\mathbf{max}}$

with the tendency $M \rightarrow M_{min}$	where the run-up time is of no importance (low switching frequency)
with the tendency $M \rightarrow M_{max}$	if a short run-up time is important (high switching frequency).

47.4 Shaft-mounted roller table geared motor drive

This solution has been applied with success in many projects.
Figure 47.4.1 compares the space requirement of various types of drive.

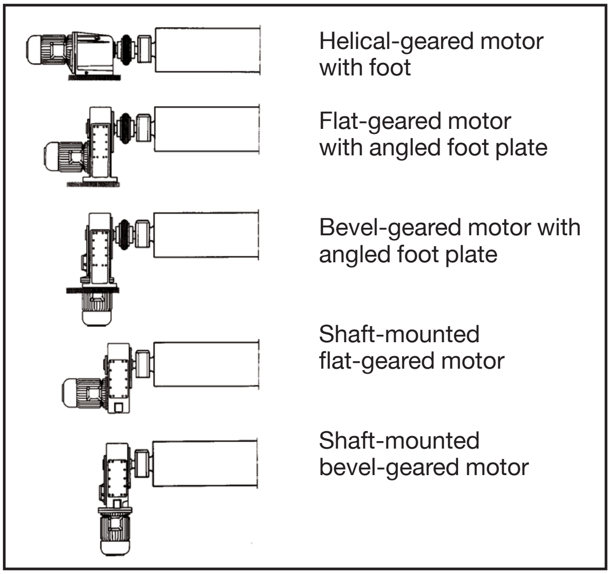


Figure 47.4.1
Comparison of the space requirement when using various types of drive

Figure 47.4.2 shows the principle and **Figure 47.4.3** an actual assembly: A shaft-mounted gear unit is mounted onto the journal end of the roller by means of a hollow shaft. No foundation or coupling required. A torque arm is provided in the design to absorb the reaction torque, but there is a simpler and more cost effective solution if the gear unit enclosure is braced directly by a prestressed rubber buffer as shown in **Figure 47.4.4**.

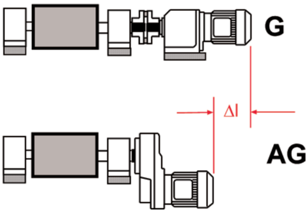


Figure 47.4.2
Principle of the single drive with slip-on roller-table geared motor (AG) by comparison with drive through a coupling (G)
Difference in space requirement: Δl

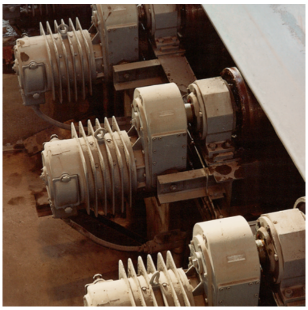


Figure 47.4.3
Slip-on roller-table geared motor with hollow shaft and simple torque restraint on the gear box at ITALSIDER, Taranto/Italy

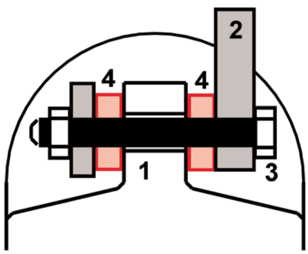


Figure 47.4.4
Principle of torque restraint on slip-on gear units by means of rubber buffers
1 – Bracing on slip-on gear unit
2 – Fastening point on the roller frame
3 – Bolt
4 – Prestressed rubber buffer

The following aspects are of importance for this solution:
- ☐ The space requirement in the direction of the roller axis is small. Where a bevel-gear unit with motor shaft and output shaft arranged at right angles is used, only the projection of the roll journal is used in the axial direction.
- ☐ The roll and the drive unit may be separated, which is not the case with the “integrated geared roller”. This means that manufacture of a robust roller and a precise gear unit is possible. Spares holdings are simplified.
- ☐ The drive unit floats on the roller shaft, and thus follows, without being forced, the tumbling motion that is unavoidable under heavy loading.
- ☐ As the shock-absorbing effect of the highly resilient coupling is absent, torque restraint must be implemented using rubber buffers.
- ☐ Removing the shaft-mounted gear unit after it has been in operation for a long time can be made a great deal easier if appropriate measures have been taken at the project stage for the roller shaft.

48 Torque motor

The torque motor has a broad range of applications, particularly in materials handling technology. This is an electric motor of special design which is ***built to run***, but ***is compelled to remain stalled***. There are some important aspects of the design of these special drives to be taken into consideration; these will be explained below on the example of some typical applications.

48.1 Difference between a torque motor and a solenoid

While the solenoid can only rotate through a limited angular path < 360° and must therefore always rotate from a specific initial position to a specific end position, the torque motor can pass through any angular path, including multiple revolutions, before it comes up against a fixed stop at any point (**Figure 48.1.1**). ***The torque motor may also be compared with a coil spring, which permits an infinitely long spring deflection, while developing a constant spring force***. A mechanical spring cannot exhibit this characteristic (**Figure 48.1.2**). The torque motor corresponds to a normal three-phase induction motor in its construction. A special design of winding with a relatively high number of poles (generally 12 poles for
500 r/min at 50 Hz) and a low magnetic flux density ensure that its rotor can be brought to a halt as often as required and held there under full voltage. It develops a torque which it applies against the load.

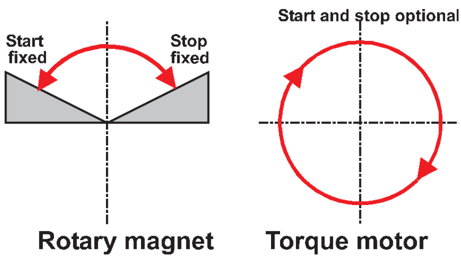


Figure 48.1.1
Principle of the rotary magnet
and the torque motor

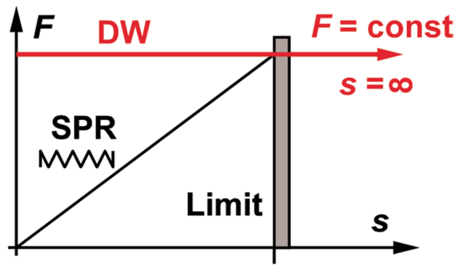


Figure 48.1.2
Comparison of spring characteristics
SPR – Spring, DW – Torque motor

If the load yields, the drive follows. As an integral fan would be useless, as it is not rotating, the fan is generally omitted or a permanently operating independent fan is used. The relatively high heat loss must be dissipated by radiation in the case of a non-ventilated design. Relatively high levels of stator housing heating are the consequence. But in contrast to a ventilated normal drive motor, the winding temperature is only a little higher than the casing temperature. For example, the casing temperature may be in excess of 100 °C without the winding being put at risk if class F insulating material is used.

48.2 Selection according to starting torque and speed

As a torque motor generally develops a torque at a standstill – i.e. at a speed n = 0 – its output is also $P = 0$. ***For this reason, geared torque motors are not classified by output (in kW), but by starting torque M_A (in Nm)***. The standard index series R 10 is suitable as a torque classification with its increments of 25 %:

12,5	16	20	25	32	40	50	63	80	100	
125	160	200	250	320	400	500	630	800	1000	Nm

The starting torque required is a result of the pressure or tractive force required (in N) and the lever arm. The speed may be determined from the time available to cover an angular or linear distance. This time should be selected to be as great as possible if it is not predetermined by cyclical operation. A low speed can then be calculated for the drive station. By contrast with the normal geared motors which are classified by output power, geared torque motors which are classified by torque are ***the more cost-effective the lower their speed rating selected*** (**Figure 48.2**).

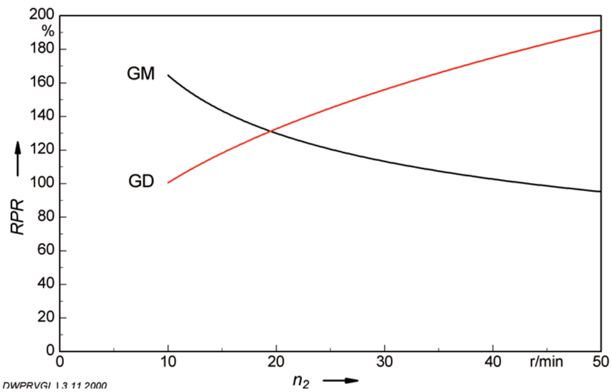


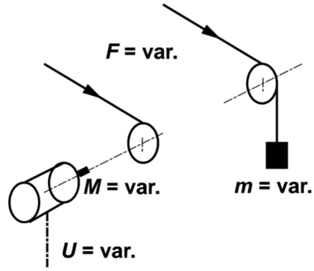
Figure 48.2
Example of the relative price PRP of geared motors (GM) and geared torque motors (GD) as a function of speed of rotation (n_2)

48.3 Drawing or tightening with adjustable force

In the manufacture of woven wire mesh, the warp must be kept under a tension which must be variable according to wire thickness and pattern. Variable suspended weights m as shown in **Figure 48.3** would be a simple solution, but this requires a greater effort on a changeover and could not be automated.

Where torque motors are used as tensioners, the starting torque M_A and thus the tension F can be adjusted precisely and maintained constant through the supply voltage applied.

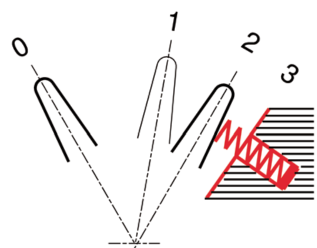
Figure 48.3
Torque motors for tensioning the warp in the manufacture of woven wire mesh
F – Tension in the warp
M – Starting torque of the torque motor
U – Supply voltage to the torque motor
m – Suspended weight (replaced by the torque motor)



48.4 Presser for switches or covers

In certain applications, there is a requirement that actuating elements such as railway switches, flaps, sliders or levers are held up against the stop in their end position under pressure. If the drive is switched off in the end position, the actuating element can impact too heavily against the stop – because of motor overrun – if the limit switch is adjusted too tightly. Should, however, the stop yield through deformation, there is a risk that form-fit is not achieved and the function of the system is jeopardised. The torque motor provides a solution with a more assured function. If the actuating element (e. g. the blade of the points) hits the limiter at the end position with an impact, uncontrollably high impact forces arise from the mass action of the rotor, which lie far beyond the forces resulting from the starting torque. Deformation energy can be applied at the stop from the stored flywheel energy. These forces also occur if the drive is switched off shortly before reaching the end position, as the flywheel energy of the rotor remains. To protect the actuating elements, the power transmission components and the gear unit components, it is therefore necessary to introduce the closing process not suddenly, but in a gradual, damped fashion. If a resilient member (**Figure 48.4.1**), e. g. a spring, a highly resilient coupling or a metal component has to be deformed before the end position, a torque is demanded from the drive.

Figure 48.4.1
Damping of the blade of points at the end position



A geared torque motor with normal, stiff characteristic graph (**Figure 48.4.2**) will generate the torque demanded of it without declining noticeably in speed when moving from position 2 to 3: It will, thus, impact the end stop with practically all its energy of rotation.

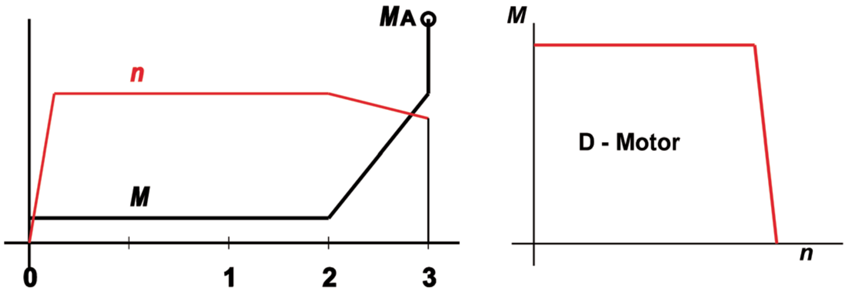


Figure 48.4.2 Speed-torque characteristic graph on a torque motor with normal, stiff characteristic graph (rectangular characteristic graph)

Because of the application of a special rotor, the drive acquires a pronounced slip characteristic and therefore declines in speed considerably on the way from position 2 to position 3 (**Figure 48.4.3**).
If the speed declines to around 50 % of the synchronous speed, the forces in the blocking phase would amount to only around 25 % by comparison with the computed values.

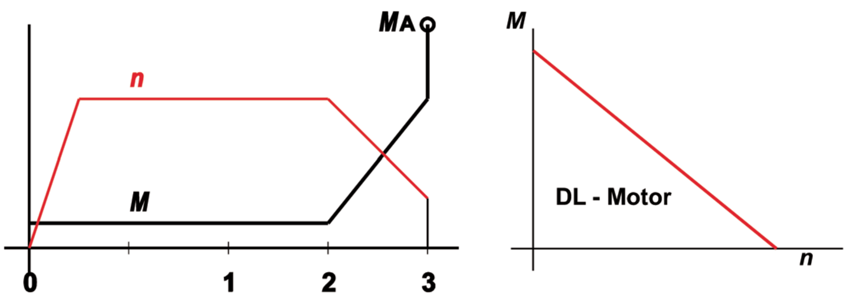
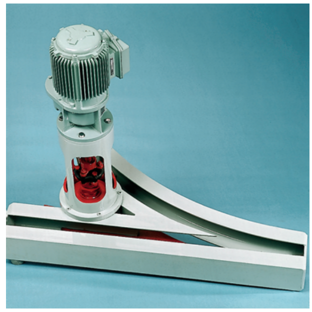
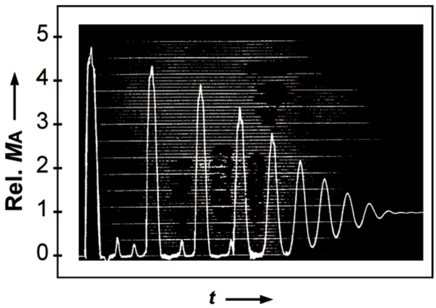


Figure 48.4.3 Speed-torque characteristic graph on a torque motor with special slip characteristic graph (triangular characteristic graph)

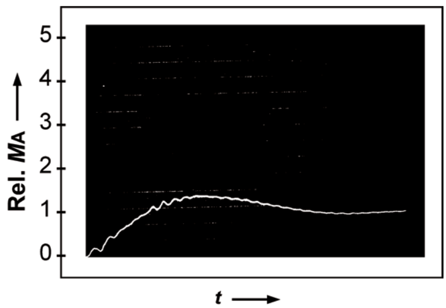
If no significant load torque occurs in the setting range, geared torque motors for pressers, switches, etc. should, where possible, be designed with a special characteristic graph (***triangular characteristic graph***) as shown in Figure 48.4.3 and be ***braked steadily before reaching the limit position.***
Where a spring is used, however, (Figure 48.4.1) the useful pressure is reduced. It is therefore recommended that a highly resilient, backlash-free coupling be used, for example, or that the actuating member be designed such that it permits a certain material deformation.

Figure 48.4.4
Geared torque motor as a presser drive on a switch





Rectangular characteristic and harsh stop in accordance with Figure 48.4.2

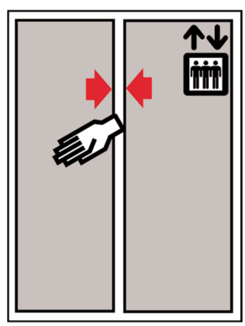


Triangular characteristic and soft stop in accordance with Figure 48.4.3

Figure 48.4.5
Oscillogram of the torque in relation to the starting torque M_A of a torque motor when the tongue of the switch meets the stop

In the case of automatic or semiautomatic door closure – e. g. in passenger lifts – there are two important requirements which can be fulfilled elegantly with torque motors (**Figure 48.4.6**):

Figure 48.4.6
Closing lift doors with torque motors
Prevent the risk of an accident by secure closing, limitation of the closing force.



48.5 Transition or transfer drive

On certain materials handling equipment (e. g. overhead chain conveyors), the main line is driven at various, adjustable speeds so that the delivery speed can be matched to the operational process. Individual pieces of the material conveyed are often taken from this main line for reasons associated with the production process (e. g. suspended ladles). To this end, a short auxiliary conveyor – the transfer – is mechanically lokked with the main conveyor (**Figure 48.5.1**) to accept the selected item onto the side-conveyor.

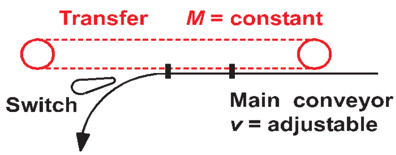


Figure 48.5.1
Diagram of a transfer drive in a overhead chain circular conveyor

To achieve shock-free and smooth transfer, the side line must run absolutely synchronously with the main line, and the transfer drive should develop the torque required for its section. The transfer drive should, therefore, neither attempt to pull the main line on its own, nor should it apply additional loading to this. An attempt to solve this task with a steplessly adjustable drive demands very complex control technology. This drive task may be solved simply using torque motors without any sophisticated control technology by applying the following principle:
In the working range of a normal three-phase induction motor – starting from no-load operation – the torque is always varied independently (e. g. by a changing load) and the speed necessarily has to adjust itself (**Figure 48.5.2**).

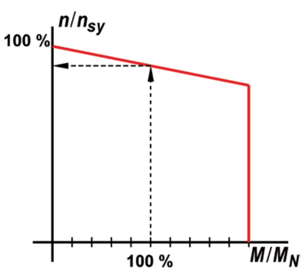


Figure 48.5.2
Torque-speed characteristic of a three-phase induction motor

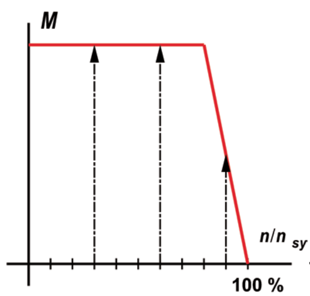


Figure 48.5.3
Speed-torque characteristic of a three-phase induction motor

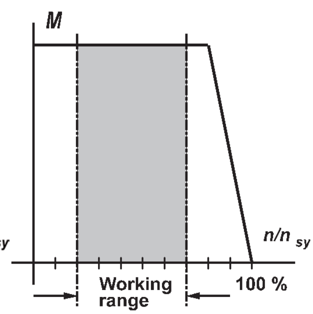


Figure 48.5.4
Operation of a torque motor as a transition or transfer drive

The rated torque of this drive is only a value specified for the rating plate taking into consideration the thermal limit: In fact, however, the drive will supply any torque demanded of it, as long as this remains below the breakdown torque. Should this working range be translated, however, in the range between starting torque and breakdown torque, it is possible to work with an independently variable speed (i.e. enforce a speed) and the torque will have to follow in accordance with the speed-torque characteristic (**Figure 48.5.3**). The torque developed by a torque motor is roughly constant between starting torque and breakdown torque; should the working range then be placed in this range (**Figure 48.5.4**), a largely constant torque will be generated at all speeds.
The geared torque motor is thus ideally suited as a transfer or transition drive.
In order to improve heat dissipation, these drives – by contrast with pressers for switches or flap – can usefully be designed with integral fans.
From the thermal point of view, operation with enforced speed is less critical than at a standstill at full voltage with a stalled rotor.

48.6 Cable reels

In the case of tracked vehicles connected to the mains supply – e. g. mobile slewing or portal cranes – the power is often supplied via a rubber insulated cable which must always be kept under tension in order to prevent damage. If the distance to be covered is very short, the cable can be wound onto a drum mounted on the vehicle wound by a coil spring. However, the spring deflection is not sufficient for a longer distance: In this case, a drive with an “infinitely long spring deflection” – the geared torque motor – is required.
Should the crane illustrated in **Figure 48.6** move towards the anchor point of the cable, the geared torque motor can operate as a motor. The speed is determined by the travelling speed of the crane. If the working range is set out such that the cable drum can retract at approximately 80 % of the synchronous speed at maximum speed of travel, the cable retractor will operate with a limited and constant torque. As the reel diameter does not change substantially, the tension in the cable is also approximately constant. This is very important with a view to protecting the cable.
When the crane stops, the cable retractor remains switched on and holds the cable under tension, thus preventing undesirable unwinding or slack in the cable.
When the crane passes the fastening point for the cable, the direction of rotation of the cable drum reverses: The cable is unrolled. The geared torque motor thus transfers into the plugging range and functions as a brake. Since the torque characteristic graph continues practically horizontally in this range, the braking force is approximately equal to the tension and, for its part, ensures trouble-free running.
The thermal loading on the geared torque motor is substantially higher when running counter to the rotating field than at a standstill at full voltage: The model should take account of this fact if the proportion of duty as a brake is relatively high.

In some applications, the cable retractor can also be switched on and off with the cranes travelling gear. When the crane is stationary, a mechanical brake will then have to be employed to prevent backward movement of the drum. The additional effort required for the brake can be compensated for, depending on the position of the individual case, by making the geared torque motor smaller which need then only be rated for short-time duty or intermittent periodic duty.
Figure 48.6 illustrates the relatively simple circuit technology: Despite the alternating direction of rotation of the retractor drum and despite variable crane travelling speed, the retractor remains always connected to the same direction of rotation and without the need for voltage variation or speed variation.
If the retractor diameter is roughly equal (which is the case with flat, one or two layer drums) there is necessarily a constant tension in the cable, without any control devices required.

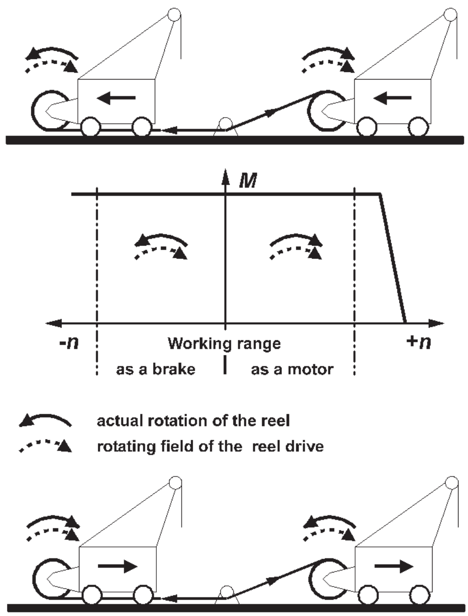


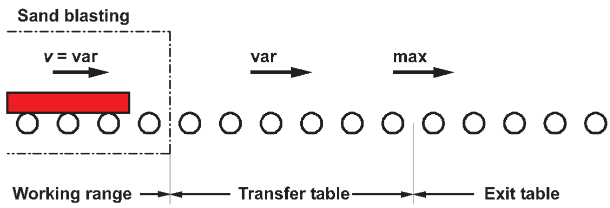
Figure 48.6
Diagram for the operation of a torque motor as a cable retractor

48.7 Transfer via frictional connection

There is, for example, a special situation in a transfer roller table between a sand blasting machine, which must run at adjustable speeds because of the different steel components, and a delivery roller table, which is intended to operate only at a constant (i.e. maximum) speed.

The transfer roller table must now accept the material being transported at the end of the main roller table and at the adjustable speed prevailing at the time and may only accelerate up to the maximum speed of the delivery roller table once the material has left the main roller table.
Here, too, a solution with adjustable drives for the transfer roller table would entail significant effort in the control technology. Suitably rated torque motors, or torque motors with torque modified through the voltage, will initially accept the variable speed imposed on them by the friction transfer between roll and material transported. They should not turn so that no grooves are created in the material transported. Only when the main roller table is no longer controlling the speed will the transfer roller table accelerate.

Figure 48.7
Diagram for a transfer roller table between processing and delivery



The geared torque motor is thus ideally suited as a transfer or transition drive.
In order to improve heat dissipation, these drives – by contrast with pressers for switches or flaps – can usefully be designed with integral fans. From the thermal point of view, operation with enforced speed is less critical than at a standstill at full voltage with a braked rotor.

48.8 Summary

The torque motor is a relatively slight variation on the three-phase cage motor; it can be used to solve, simply, special tasks in materials handling technology. In many cases it can replace complex control systems thus being easy to operate and secure in its function.

XI APPENDIX

49 Formulae and units in drive technology

The International System of Units, identified internationally as SI units (**S**ystème **I**nternational d'Unités) was introduced in 1960 by a resolution of the 11th "General conference for weights and measures" with the ISO recommendation R 1000 of February 1969. DIN 1301 (current version 1993) was developed on this basis and the law governing units of measurement (in short, the Unit Law), which came into force on 5th July 1970, govern the introduction of the new units in business and official matters. SI units are "coherent", that is to say, all the units are related by equations in which there are no numerical factors other than 1. They are also "absolute", i.e. none of them is dependent on properties such as the value of gravitational acceleration at the surface of the earth. SI units make a firm distinction between mass with kg as its basic unit, measured for instance by weighing, and the forces (force due to weight) of these masses,created by gravitational acceleration, which have the unit N (Newton).
1 N is the force which will accelerate a mass of 1 kg by 1 m/s^2.
Along with those countries who have always used the metric system, those countries who have made the transition from the imperial to the metric systems also use SI units as the basis for their national standards.

49.1 SI basic units

Size	Unit symbol	Name
Length	m	Metre
Mass	kg	Kilogram
Time	s	Second
Electrical current	A	Ampere
Thermodynamic temperature	K	Kelvin
Luminous intensity	cd	Candela

49.2 Decimal multiples and submultiples of units

Factor	Prefix	Prefix symbol
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{2}	Hekto	h
10	Deka	da
10^{-1}	Dezi	d
10^{-2}	Zenti	c
10^{-3}	Milli	m
10^{-6}	Mikro	
10^{-9}	Nano	n
10^{-12}	Piko	p
10^{-15}	Femto	f
10^{-18}	Atto	a

The prefix symbol is sometimes used on its own in front of the unit symbol.
This is incorrect.
For example, 10^{-6} m = 1µm = 1 micrometer should not be written as 1 µ = 1 micron.

49.3 Letter symbols and SI units

Area	Symbol	Meaning	Unit Symbol	Name
Geometry	***A***	Area	m^2	Square metre
	a	Distance	m	Metre
	α, β, γ	Angle	rad	Radian
			°	Degree
	b	Breadth	m	Metre
	d, δ	Thickness	m	Metre
	d	Diameter	m	Metre
	h	Height	m	Metre
	l	Length	m	Metre
	r	Radius	m	Metre
	s	Length of path	m	Metre
	V	Volume	m^3	Cubic metre
Time	***a***	Acceleration	m/s^2	
	α	Angular acceleration	rad/s^2	
	f	Frequency	Hz	Hertz
	g	Acceleration of free fall	m/s^2	
	n	Rotational frquency (speed)	1/s r/min	
	ω	Angular frequency	rad/s	
	T	Time constant	s	Second
	t	Time, time period, duration	s	Second
	v	Linear speed	m/s	
Mechanics	***E***	Modulus of elasticity	Pa	Pascal
	F	Force	N	Newton
	G	Force due to weight	N	Newton
	J	Mass moment of inertia	kgm^2	
	M	Torque	Nm	
	m	Mass	kg	Kilogram
	P	Power	W	Watt
	p	Pressure	Pa	Pascal
	ρ	Density	kg/m^2	
	σ	Tensile stress, compressive stress, bending stress	Pa	Pascal
	W	Work, energy	J	Joule
	η	Efficiency	1	
	μ	Coefficient of friction	1	

Area	Symbol	Meaning	Unit Symbol	Name
Heat	α	Temperature coefficient	1/K	
	T	Thermodynamic (Kelvin) temperature	K	Kelvin
	t, ϑ	Celsius temperature	°C	Degree Celsius
	Δ***T***, $\Delta\vartheta$	Temperature difference, temperature rise	K	Kelvin
Electricity	***C***	Electrical capacitance	F	Farad
	G	Electrical conductivity	S	Siemens
	I	Electrical current	A	Ampere
	J, S, G	Electrical current density	A/m^2	
	P	Active power	W	Watt
	Q, Pq	Reactive power	W, var	Var
	R	Equivalent resistance	Ω	Ohm
	S, Ps	Apparent power	W, VA	Volt-ampere
	U	Electrical voltage	V	Volt
	X	Reactance	Ω	Ohm
	Z	Impedance	Ω	Ohm
Magnetism	***B***	Magnetic flux density, induction	T	Tesla
	Φ	Magnetic flux	Wb	Weber
	H	Magnetic field strength	A/m	
	L	Inductance	H	Henry

49.4 Important equations with physical quantities

Translation	Rotation
$v = \frac{s}{t}$	$\omega = 2 \cdot \pi \cdot n$
	$v = \omega \cdot r = 2\pi \cdot n \cdot r$
$s = v \cdot t$	$\varphi = \omega \cdot t = 2\pi \cdot n \cdot t$
$a = \frac{v}{t_a}$	$\alpha = \frac{\omega}{t_a}$
	$M = F \cdot r$
$P = F \cdot v$	$P = M \cdot \omega$
$F = m \cdot a$	$M = J \cdot \alpha$
$W = F \cdot s$	$W = M \cdot \varphi$
$W = \frac{m \cdot v^2}{2}$	$W = \frac{J \cdot \omega^2}{2}$
$W_{pot} = m \cdot g \cdot h$	$J = m \cdot r^2$

49.5 Important definitions

Efficiency	$\eta = \frac{P_{ab}}{P_{auf}} = \frac{P_{auf} - V}{P_{auf}} = 1 - \frac{V}{P_{auf}}$	P_{auf} – Power input P_{ab} – Power output V – Losses
Translation	$i = \frac{n_1}{n_2}$	n_1 – Input speed n_2 – Output speed

49.6 Important numerical value equations

The units indicated previously should be used for numerical value equations or tailored equations with physical quantities.
SI units should always refer to a mass in kg.

49.6.1 Power

Lifting motion

$$P = \frac{m \cdot g \cdot v}{\eta \cdot 1000}$$

Translation

$$P = \frac{F_R \cdot v}{1000}$$

$$F_R = \mu \cdot m \cdot g$$

Rotation

$$P = \frac{M \cdot n}{9550}$$

P	–	Power in kW
F_R	–	Frictional resistance in N
m	–	Mass in kg
g	–	Gravitational acceleration (9.81 m/s²)
v	–	Velocity in m/s
η	–	Efficiency as a decimal fraction
μ	–	Coefficient of friction
M	–	Torque in Nm
n	–	Rotational speed in r/min

49.6.2 Torque

$$M = F \cdot r$$

$$M = \frac{9550 \cdot P}{n}$$

M	–	Torque in Nm
F_R	–	Frictional resistance in N
r	–	Lever arm (radius) in m
P	–	Power in kW
n	–	Rotational speed in r/min

49.6.3 Work

$$W = F \cdot s = m \cdot g \cdot s$$

$$W = \frac{J \cdot n^2}{182{,}5}$$

W	–	Work (energy) in Nm = Ws = J
F	–	Force in N
s	–	Path length in m
m	–	Mass in kg
g	–	Gravitational acceleration (9.81 m/s²)
J	–	Mass moment of inertia in kgm²
n	–	Rotational speed in r/min

49.6.4 Acceleration rate or braking time

$$t_a = \frac{J \cdot n}{9{,}55 \cdot M_a}$$

t_a – Acceleration rate or braking time in s
J – Mass moment of inertia in kgm^2
n – Rotational speed in r/min
M_a – Acceleration rate/braking torque in Nm

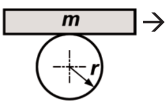
49.6.5 Mass moment of inertia and flywheel effect

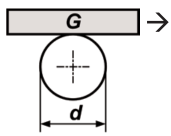
The term flywheel effect GD^2 which was previously used on the Technical Measurement System has not been adopted in the SI. The different units and the different definition must therefore be heeded in calculation that use the mass moment of inertia mr^2.

Solid cylinder $J = \frac{1}{2} \cdot m \cdot r_a^2 = \frac{1}{32} \cdot 1000 \cdot \pi \cdot \varsigma \cdot l \cdot d_a^4 = 98 \cdot \varsigma \cdot l \cdot d_a^4$

Hollow cylinder $J = \frac{1}{2} \cdot m \cdot (r_a^2 + r_i^2) = \frac{1}{32} \cdot 1000 \cdot \pi \cdot \varsigma \cdot l \cdot (d_a^4 - d_i^4) = 98 \cdot \varsigma \cdot l \cdot (d_a^4 - d_i^4)$

Linear motion as a tangent to the circle





$$J = m \cdot r^2 = m \cdot \left(\frac{d}{2}\right)^2 = \frac{m \cdot d^2}{4}$$

$$GD^2 = G \cdot d^2$$

Since the weight G here is seen as a mass in kg, the numerical value of m and G is the same. The following is used to calculate the flywheel effects in mass moments of inertia:

$$J = \frac{GD^2}{4}$$

That is to say, the numerical value of GD^2 (in kpm^2) is to be divided by 4 to give the numerical value of J (in kgm^2).

Conversion of a mass action from translation to rotation $J = 91{,}2 \cdot m \cdot \frac{v^2}{n^2}$

J – Mass moment of inertia in kgm^2
m – Mass in kg
r – Radius in m
d_a – External diameter in m
d_i – Inside diameter in m
r_a – Outside radius in m
r_i – Inside radius in m
l – Length in m
ς – Density in kg/dm^3
v – Velocity in m/s
n – Rotational speed in r/min

Factor of inertia

The *inertia factor FI* (Factor of Inertia) is the relationship between all masses driven by the motor, including the motor rotor‘s inertia torque, converted to the motor speed, to the motor rotor‘s inertia torque, thus

$$FI = \frac{J_{total}}{J_{rotor}} = \frac{J_{extern1} + J_{rotor}}{J_{rotor}}$$

49.6.6 Electrical characteristic values of the drive motor

Input

$$P_{auf} = \frac{\sqrt{3} \cdot U \cdot I \cdot \cos\varphi}{1000}$$

Output

$$P_{ab} = \frac{\sqrt{3} \cdot U \cdot I \cdot \cos\varphi \cdot \eta}{1000}$$

Temperature rise

$$\Delta T = \frac{R_w - R_k}{R_k} \cdot (235 + \vartheta_k)$$

P – Power in kW
U – Main conductor voltage in V
I – Main conductor current in A

$\cos\varphi$ – Power factor as a decimal fraction

η – Motor efficiency as a decimal fraction
ΔT – Temperature rise of the winding in K
ϑ – Temperature of the winding in °C

Index
auf – Input
ab – Output

k – when cold
w – when warm

50 Conversion factors

Since specific units are required for the numerical value equations as well as for the inputs and for the result, the conversion factors must be used.
This also applies to the characteristics of the imperial system which is still commonly used in North America.

50.1 Length

		m	dm	cm	mm	yd	ft	in	mil
1 m	=	1	10	100	1000	1.094	3.281	39.370	39.4×10^{3}
1 dm	=	0.1	1	10	100	0.1094	0.3281	3.937	3937
1 cm	=	0.01	0.1	1	10	10.9×10^{-3}	32.8×10^{-3}	0.3937	393.7
1 mm	=	0.001	0.01	0.1	1	1.09×10^{-3}	3.28×10^{-3}	39.4×10^{-3}	39.37
1 yd	=	0.9144	9.144	91.44	914.4	1	3	36	36×10^{3}
1 ft	=	0.3048	3.048	30.48	304.8	0.3333	1	12	12×10^{3}
1 in	=	25.4×10^{-3}	0.2540	2.540	25.40	27.8×10^{-3}	83.3×10^{-3}	1	1000
1 mil	=	25.4×10^{-6}	254×10^{-6}	2.54×10^{-3}	25.4×10^{-3}	27.8×10^{-6}	83.3×10^{-6}	1×10^{-3}	1

1 mile	(statute or British mile)		= 1760 yd	= 5280 ft	= 1609.344 m
1 n mile	(nautical mile)		= 6080 ft	= 1.853 km	
1 km	= 39370 in	= 3281 ft	= 1093.6 yd	= 0.6214 mile	= 0.5396 n mile
1 fathom		= 6 ft	= 1.8288 m		

50.2 Area

		m^2	dm^2	cm^2	mm^2	yd^2	ft^2	in^2	CM
1 m^2	=	1	100	10×10^3	1×10^6	1.196	10.764	1550	–
1 dm^2	=	0.01	1	100	10×10^3	12×10^{-3}	0.1076	15.50	–
1 cm^2	=	0.1×10^{-3}	0.01	1	100	0.12×10^{-3}	1.08×10^{-3}	0.1550	197×10^3
1 mm^2	=	1×10^{-6}	0.1×10^{-3}	0.01	1	1.2×10^{-6}	10.8×10^{-6}	1.55×10^{-3}	1.97×10^3
1 yd^2	=	0.8361	83.61	8361	836×10^3	1	9	1296	–
1 ft^2	=	92.9×10^{-3}	9.290	929.03	92.9×10^3	0.1111	1	144	183×10^6
1 in^2	=	0.645×10^{-3}	64.5×10^{-3}	6.4516	645.16	772×10^{-6}	6.94×10^{-3}	1	1.27×10^6
1 CM	=	–	–	5.07×10^{-6}	0.507×10^{-3}	–	5.45×10^{-9}	0.785×10^{-6}	1

CM – circular mil – imperial unit for small areas

1 square mile	= 640 acres	= 2.590 km^2	= 259 ha
1 acre	= 4840 yd^2	= 0.405 ha	= 4047 m^2
1 km^2	= 0.386 sq. mile	= 100 ha	= 10 000 a
1 ha	= 100 a	= 2.471 acres	= 11959.6 yd^2
1 a	= 100 m^2	= 119.6 yd^2	= 1076.4 ft^2

50.3 Volume

		m^3	dm^3	cm^3	yd^3	ft^3	in^3	gal (UK)	gal (US)
1 m^3	=	1	1000	1×10^6	1.3079	35.32	61.02×10^3	220	264.2
1 dm^3	=	1×10^{-3}	1	1000	1.3×10^{-3}	35.3×10^{-3}	61.02	0.22	0.2642
1 cm^3	=	1×10^{-6}	1×10^{-3}	1	1.3×10^{-6}	35.3×10^{-6}	61×10^{-3}	0.22×10^{-3}	0.26×10^{-3}
1 yd^3	=	0.765	764.6	765×10^3	1	27	46.7×10^3	168.2	202
1 ft^3	=	28.3×10^{-3}	28.32	28.3×10^3	37×10^{-3}	1	1728	6.229	7.481
1 in^3	=	16.4×10^{-6}	16.4×10^{-3}	16.39	21.4×10^{-6}	579×10^{-6}	1	3.6×10^{-3}	4.3×10^{-3}
1 gal (UK)	=	4.55×10^{-3}	4.546	4546	5.95×10^{-3}	0.1605	277	1	1.201
1 gal (US)	=	3.79×10^{-3}	3.785	3785	4.95×10^{-3}	0.1337	231	0.8327	1

1 bushel (UK)	= 8 gal (UK)	= 64 pt (UK) = 36.37 l
1 bushel (US)	= 0.969 bu (UK)	= 35.24 l
1 pint (UK)	= 1/8 gal (UK)	= 0.5682 l
1 liqu. pt (US)	= 1/8 gal (US)	= 0.4732 l
1 l	= 1.76 pt (UK)	= 2.113 liqu. pt (US)

50.4 Force

		N	kgf	p	dyn	tonf (UK)	lbf	ozf
1 N	=	1	0.1020	102.0	1×10^{5}	100.4×10^{-6}	0.2248	3.597
1 kgf	=	9.807	1	1000	981×10^{3}	0.984×10^{-3}	2.205	35.27
1 p	=	9.81×10^{-3}	1×10^{-3}	1	980.7	0.984×10^{-6}	2.2×10^{-3}	35.3×10^{-3}
1 dyn	=	1×10^{-5}	1.02×10^{-6}	1.02×10^{-3}	1	1×10^{-9}	2.25×10^{-6}	36×10^{-6}
1 tonf (UK)	=	9964	1016	1.02×10^{6}	996×10^{6}	1	2240	35.8×10^{3}
1 lbf	=	4.448	0.4536	453.6	445×10^{3}	446×10^{-6}	1	16
1 ozf	=	0.278	28.4×10^{-3}	28.35	27.8×10^{3}	27.9×10^{-6}	62.5×10^{-3}	1

1 (long) ton (UK)	= 160 stones	= 2240 lb	= 1.016 t
1 (short) ton (US)	= 142.9 stones	= 2000 lb	= 0.907 t
1 stone	= 14 lb	= 224 oz	= 6.35 kg
1 ton	= 20 cwt		
1 cwt (UK)	= 4 quarters	= 8 stones	= 112 lb
1 cwt (US)	= 100 lb	= 45.36 kg	
1 t	= 1000 kg	= 0.984 ton (UK)	= 1.101 ton (US)

50.5 Velocity

		km/h	m/min	m/s	mile/h	ft/min	f t/s	in/s
1 km/h	=	1	16.667	0.2778	0.6214	54.68	0.9113	10.936
1 m/min	=	0.06	1	16.7×10^{-3}	37.3×10^{-3}	3.281	54.7×10^{-3}	0.656
1 m/s	=	3.6	60	1	2.237	196.85	3.281	39.37
1 mile/h	=	1.609	26.82	0.4470	1	88	1.467	17.6
1 ft/min	=	18.3×10^{-3}	0.3048	5.08×10^{-3}	11.4×10^{-3}	1	16.7×10^{-3}	0.2
1 ft/s	=	1.097	18.288	0.3048	0.6818	60	1	12
1 in/s	=	91×10^{-3}	1.524	25.4×10^{-3}	56.8×10^{-3}	5	83.3×10^{-3}	1

50.6 Torque

		Nm	cNm	kgfm	cpm	lbf x ft	lbf x in	ozf x in
1 Nm	=	1	100	0.10197	10.2 x 10^{3}	0.73756	8.8507	141.61
1 cNm	=	0.01	1	1.02 x 10^{-3}	101.97	7.376 x 10^{-3}	88.5 x 10^{-3}	1.4161
1 kgfm	=	9.8067	980.67	1	100 x 10^{3}	7.233	86.796	1389
1 cpm	=	98.1 x 10^{-6}	9.81 x 10^{-3}	10 x 10^{-6}	1	72.3 x 10^{-6}	868 x 10^{-6}	13.9 x 10^{-3}
1 lbf x ft	=	1.356	135.6	0.1383	13.8 x 10^{3}	1	12	192
1 lbf x in	=	0.1129	11.29	11.5 x 10^{-3}	1152	83.3 x 10^{-3}	1	16
1 ozf x in	=	7.062 x 10^{-3}	0.7062	0.72 x 10^{-3}	72.01	5.21 x 10^{-3}	62.5 x 10^{-3}	1

50.7 Power

		kW	mhp	hp	kgfm/s	ft x lbf/s	kcal/s	Btu/s
1 kW	=	1	1.360	1.341	102.0	737.6	0.2388	0.9478
1 mhp	=	0.7355	1	0.9863	75	542.5	0.1757	0.6971
1 hp	=	0.7457	1.014	1	76.04	550	0.1781	0.7068
1 kgfm/s	=	9.81 x 10^{-3}	13.33 x 10^{-3}	13.15 x 10^{-3}	1	7.233	2.342 x 10^{-3}	9.295 x 10^{-3}
1 ft x lbf/s	=	1.36 x 10^{-3}	1.84 x 10^{-3}	1.82 x 10^{-3}	0.1383	1	0.324 x 10^{-3}	1.285 x 10^{-3}
1 kcal/s	=	4.1868	5.692	5.615	426.9	3088	1	3.968
1 Btu/s	=	1.055	1.435	1.415	107.6	778.2	0.2520	1

50.8 Mass moment of inertia and flywheel effect

		kgm² (*mr²*)	kgfm² (*GD²*)	lbf x ft² (*WK²*)	kpms²	ft x lbf s²
1 kgm² (mr²)	=	1	4	23.73	0.102	0.7376
1 kgfm² (GD²)	=	0.25	1	5.933	25.5 x 10^{-3}	0.1844
1 lbf x ft² (WK²)	=	42.1 x 10^{-3}	0.1686	1	4.30 x 10^{-3}	31.1 x 10^{-3}
1 kpms²	=	9.807	39.23	232.7	1	7.233
1 ft x lbf s²	=	1.356	5.423	32.17	0.1383	1

50.9 Pressure

		Pa (N/m^2)	bar	kgf/m^2	kgf/cm^2	kgf/mm^2	lbf/yd^2
1 Pa	=	1	1×10^{-5}	0.102	10.2×10^{-6}	0.102×10^{-6}	0.188
1 bar	=	1×10^{5}	1	10.2×10^{3}	1.02	10.2×10^{-3}	18.8×10^{3}
1 kgf/m^2	=	9.81	98.1×10^{-6}	1	0.1×10^{-3}	1×10^{-6}	1.843
1 kgf/cm^2	=	98.1×10^{3}	0.981	10×10^{3}	1	0.01	18.4×10^{3}
1 kgf/mm^2	=	9.81×10^{6}	98.1	1×10^{6}	100	1	1.84×10^{6}
1 lbf/yd^2	=	5.32	53.2×10^{-6}	0.543	54×10^{-6}	0.54×10^{-6}	1
1 lbf/ft^2	=	47.88	479×10^{-6}	4.882	0.488×10^{-3}	4.88×10^{-6}	9
1 lbf/in^2	=	6.89×10^{3}	68.9×10^{-3}	703	70.3×10^{-3}	0.703×10^{-3}	1296
1 $tonf/in^2$	=	15.4×10^{6}	154	1.58×10^{6}	157.5	1.575	2.9×10^{6}

		lbf/ft^2	lbf/in^2	$tonf/in^2$
1 Pa	=	20.88×10^{-3}	145×10^{-6}	64.75×10^{-9}
1 bar	=	2.088×10^{3}	14.5	6.475×10^{-3}
1 kgf/m^2	=	0.2048	1.42×10^{-3}	0.64×10^{-6}
1 kgf/cm^2	=	2.05×10^{3}	14.223	6.4×10^{-3}
1 kgf/mm^2	=	205×10^{3}	1.422×10^{3}	0.6349
1 lbf/yd^2	=	0.1111	772×10^{-6}	0.345×10^{-6}
1 lbf/ft^2	=	1	6.94×10^{-3}	3.1×10^{-6}
1 lbf/in^2	=	144	1	0.446×10^{-3}
1 $tonf/in^2$	=	0.323×10^{6}	2240	1

1 N/m^2 = 1 Pa (Pascal)
1 mbar = 1 hPa (Hektopascal)

50.10 Temperature

		°F	°C	K	°Réau	°R
v °F	=	v	5/9 (v - 32)	5/9 (v - 32) + 273	4/9 (v - 32)	v + 460
w °C	=	9/5 w + 32	w	w + 273	4/5 w	9/5 w + 492
x K	=	9/5 x - 460	x - 273	x	4/5 (x - 273)	9/5 x
y °Réau	=	9/4 y + 32	5/4 y	5/4 y + 273	y	9/4 y + 492
z °R	=	z - 460	5/9 z - 273	5/9 z	4/9 z - 219	z

Reference points of temperature:

Boiling point of water:

212 °F	100 °C	373.15 K	80 °Réau	671.67 °R

Freezing point of water:

32 °F	0 °C	273.15 K	0 °Réau	491.67 °R

Absolute zero:

- 459.67 °F	- 273.15 °C	0 K	–	0 °R

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INDEX OF KEYWORDS

Starting, braking and positioning

Starting, braking and positioning – these are important aspects of the duties required of electric drives in the context of automation and rationalization.
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