The compact Lenze formula collection

Lenze

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Introduction to the 5th edition

This little collection of formulae has been put together for the dimensioning and project-planning of electrical drives.

Dimensions that are not defined in the SI-system can be converted by using the conversion tables.

The derivations of the formulae have been left out.
However, the numerical equations have been presented in such a manner that the physical relationships are apparent.

Hameln, September 1999

Contents

Dimensions and conversion

1

Fundamental units of the SI-system DIN 1301-1

Physical dimension	Name	Abbreviation
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electrical current	Ampere	A
Temperature	Kelvin	K
Substance quantity	Mol	mol
Luminous intensity	Candela	cd

Prefixes and their abbreviations as per DIN 66030

Prefix	Multip. factor for the dimen. unit	Inter-national prefix char.	Representation Form I Upper or lower case	Form II (lower case only)	(upper case only)
Tera	10^{12}	T	T	t	T
Giga	10^{9}	G	G	g	G
Mega	10^{6}	M	M	ma	MA
Kilo	10^{3}	k	k	k	K
Hekto	10^{2}	h	h	h	H
Deka	10^{1}	da	da	da	DA
Dezi	10^{-1}	d	d	d	D
Zenti	10^{-2}	c	c	c	C
Milli	10^{-3}	m	m	m	M
Mikro	10^{-6}	µ	u	u	U
Nano	10^{-9}	n	n	n	N
Piko	10^{-12}	p	p	p	P

Conversion of lengths

A \ B	mm	cm	m	in	ft	yd	km	mile	naut mile[1])
mm	1	10^{-1}	10^{-3}	$3.93701 \cdot 10^{-2}$	$3.28084 \cdot 10^{-3}$	$1.09361 \cdot 10^{-3}$	10^{-6}	$6.21371 \cdot 10^{-7}$	$5.39957 \cdot 10^{-7}$
cm	10	1	10^{-2}	$3.93701 \cdot 10^{-1}$	$3.28084 \cdot 10^{-2}$	$1.09361 \cdot 10^{-2}$	10^{-5}	$6.21371 \cdot 10^{-6}$	$5.39957 \cdot 10^{-6}$
m	1000	100	1	3.93701	3.28084	1.09361	10^{-3}	$6.21371 \cdot 10^{-4}$	$5.39957 \cdot 10^{-4}$
in	25.4	2.54	$2.54 \cdot 10^{-2}$	1	$8.33333 \cdot 10^{-2}$	$2.77778 \cdot 10^{-2}$	$2.54 \cdot 10^{-5}$	$1.57828 \cdot 10^{-5}$	$1.37149 \cdot 10^{-5}$
ft	304.8	30.48	$3.048 \cdot 10^{-1}$	12	1	$3.33333 \cdot 10^{-1}$	$3.048 \cdot 10^{-4}$	$1.89394 \cdot 10^{-4}$	$1.64579 \cdot 10^{-4}$
yd	914.4	91.44	$9.144 \cdot 10^{-1}$	36	3	1	$9.144 \cdot 10^{-4}$	$5.68182 \cdot 10^{-4}$	$4.93737 \cdot 10^{-4}$
km	10^{6}	10^{5}	1000	39370.1	3280.84	1093.61	1	$6.21371 \cdot 10^{-1}$	$5.39957 \cdot 10^{-1}$
mile	$1.60934 \cdot 10^{6}$	160 934	1609.34	63360	5280	1760	1.60934	1	$8.68976 \cdot 10^{-1}$
naut mile[1])	$1.852 \cdot 10^{6}$	185 200	1852	72913.4	6076.12	2025.37	1.852	1.15078	1

[1]) IIn the United Kingdom: 1 nautical mile = 1853 m

Conversion of areas

A \ B	cm^2	m^2	a	ha	km^2	in^2	ft^2	yd^2	sq mile	acre
cm^2	1	10^{-4}	10^{-6}	10^{-8}	10^{-10}	$1.55000 \cdot 10^{-1}$	$1.07639 \cdot 10^{-3}$	$1.19599 \cdot 10^{-4}$	$3.86102 \cdot 10^{-11}$	$2.47105 \cdot 10^{-8}$
m^2	10000	1	10^{-2}	10^{-4}	10^{-6}	1550.00	10.7639	1.19599	$3.86102 \cdot 10^{-7}$	$2.47105 \cdot 10^{-4}$
a	10^{6}	100	1	10^{-2}	10^{-4}	155 000	1076.39	119.599	$3.86102 \cdot 10^{-5}$	$2.47105 \cdot 10^{-2}$
ha	10^{8}	10000	100	1	10^{-2}	$1.55000 \cdot 10^{7}$	107 639	11959.9	$3.86102 \cdot 10^{-3}$	2.47105
km^2	10^{10}	10^{6}	10000	100	1	$1.55000 \cdot 10^{9}$	$1.07639 \cdot 10^{7}$	$1.19599 \cdot 10^{6}$	$3.86102 \cdot 10^{-1}$	247.105
in^2	6.45160	$6.45160 \cdot 10^{-4}$	$6.45160 \cdot 10^{-6}$	$6.45160 \cdot 10^{-8}$	$6.45160 \cdot 10^{-10}$	1	$6.94444 \cdot 10^{-3}$	$7.71605 \cdot 10^{-4}$	$2.49098 \cdot 10^{-10}$	$1.59423 \cdot 10^{-7}$
ft^2	929.030	$9.29030 \cdot 10^{-2}$	$9.29030 \cdot 10^{-4}$	$9.29030 \cdot 10^{-6}$	$9.29030 \cdot 10^{-8}$	144	1	$1.11111 \cdot 10^{-1}$	$3.58701 \cdot 10^{-8}$	$2.29568 \cdot 10^{-5}$
yd^2	8361.27	$8.36127 \cdot 10^{-1}$	$8.36127 \cdot 10^{-3}$	$8.36127 \cdot 10^{-5}$	$8.36127 \cdot 10^{-7}$	1296	9	1	$3.22831 \cdot 10^{-7}$	$2.06612 \cdot 10^{-4}$
sq mile	$2.58999 \cdot 10^{10}$	$2.58999 \cdot 10^{6}$	25899.9	258.999	2.58999	$4.01449 \cdot 10^{9}$	$2.78784 \cdot 10^{7}$	$3.09760 \cdot 10^{6}$	1	640
acre	$4.04686 \cdot 10^{7}$	4046.86	40.4686	$4.04686 \cdot 10^{-1}$	$4.04686 \cdot 10^{-3}$	$6.27264 \cdot 10^{6}$	43560.0	4840	$1.56250 \cdot 10^{-3}$	1

Conversion of volumes

A \ B	cm^3	$dm^3 = l$	in^3	ft^3	yd^3	US fl oz	Imp fl oz	US gal	Imp gal	Imp pint
cm^3	1	10^{-3}	$6.10237 \cdot 10^{-2}$	$3.53147 \cdot 10^{-5}$	$1.30795 \cdot 10^{-6}$	$3.38140 \cdot 10^{-2}$	$3.51951 \cdot 10^{-2}$	$2.64172 \cdot 10^{-4}$	$2.19969 \cdot 10^{-4}$	$1.75975 \cdot 10^{-3}$
$dm^3 = l$	1000	1	61.0237	$3.53147 \cdot 10^{-2}$	$1.30795 \cdot 10^{-3}$	33.8140	35.1951	$2.64172 \cdot 10^{-1}$	$2.19969 \cdot 10^{-1}$	1.75975
in^3	16.3871	$1.63871 \cdot 10^{-2}$	1	$5.78704 \cdot 10^{-4}$	$2.14335 \cdot 10^{-5}$	$5.54113 \cdot 10^{-1}$	$5.76744 \cdot 10^{-1}$	$4.32900 \cdot 10^{-3}$	$3.60465 \cdot 10^{-3}$	$2.88372 \cdot 10^{-2}$
ft^3	28316.8	28.3168	1728	1	$3.70370 \cdot 10^{-2}$	957.506	996.614	7.48052	6.22884	49.8307
yd^3	764 555	764.555	46656	27	1	25852.7	26908.6	201.974	168.179	1345.43
US fl oz	29.5735	$2.95735 \cdot 10^{-2}$	1.80469	$1.04438 \cdot 10^{-3}$	$3.86807 \cdot 10^{-5}$	1	1.04084	$7.8125 \cdot 10^{-3}$	$6.50527 \cdot 10^{-3}$	$5.20421 \cdot 10^{-2}$
Imp fl oz	28.4131	$2.84131 \cdot 10^{-2}$	1.73387	$1.00340 \cdot 10^{-3}$	$3.71629 \cdot 10^{-5}$	$9.60760 \cdot 10^{-1}$	1	$7.50594 \cdot 10^{-3}$	$6.25 \cdot 10^{-3}$	$5 \cdot 10^{-2}$
US gal	3785.41	3.78541	231	$1.33681 \cdot 10^{-1}$	$4.95113 \cdot 10^{-3}$	128	133.228	1	$8.32674 \cdot 10^{-1}$	6.66139
Imp gal	4546.09	4.54609	277.419	$1.60544 \cdot 10^{-1}$	$5.94606 \cdot 10^{-3}$	153.722	160	1.20095	1	8
Imp pint	568.261	$5.68261 \cdot 10^{-1}$	34.6774	$2.00680 \cdot 10^{-2}$	$7.43258 \cdot 10^{-4}$	19.2152	20	$1.50119 \cdot 10^{-1}$	$1.25 \cdot 10^{-1}$	1

Conversion of mass

A \ B	g	kg	oz	lbm	US ton
g	1	10^{-3}	$3.52740 \cdot 10^{-2}$	$2.20462 \cdot 10^{-3}$	$1.10231 \cdot 10^{-6}$
kg	1000	1	35.2740	2.20462	$1.10231 \cdot 10^{-3}$
oz	28.3495	$2.83495 \cdot 10^{-2}$	1	$6.25 \cdot 10^{-2}$	$3.125 \cdot 10^{-5}$
lbm	453.592	$4.53592 \cdot 10^{-1}$	16	1	$5 \cdot 10^{-4}$
US ton	907 185	907.185	32 000	2000	1

Conversion of energy

A \ B	J	Wh	kp m	kcal	BTU
J	1	$2.77778 \cdot 10^{-4}$	$1.01972 \cdot 10^{-1}$	$2.38846 \cdot 10^{-4}$	$9.47817 \cdot 10^{-4}$
Wh	3600	1	367.098	$8.59845 \cdot 10^{-1}$	3.41214
kp m	9.80665	$2.72407 \cdot 10^{-3}$	1	$2.34228 \cdot 10^{-3}$	$9.29491 \cdot 10^{-3}$
kcal	4186.8	1.163	426.935	1	3.96832
BTU	1055.06	$2.93071 \cdot 10^{-1}$	107.586	$2.51996 \cdot 10^{-1}$	1

Conversion of torque

A \ B	N cm	N m	kp cm	kp m	p cm	oz in	in lbs	ft lbs
N cm	1	10^{-2}	$1.01972 \cdot 10^{-1}$	$1.01972 \cdot 10^{-3}$	101.972	1.41612	$8.85075 \cdot 10^{-2}$	$7.37562 \cdot 10^{-3}$
N m	100	1	10.1972	$1.01972 \cdot 10^{-1}$	10197.2	141.612	8.85075	$7.37562 \cdot 10^{-1}$
kp cm	9.80665	$9.80655 \cdot 10^{-2}$	1	10^{-2}	1000	13.8874	$8.67962 \cdot 10^{-1}$	$7.23301 \cdot 10^{-2}$
kp m	980.665	9.80665	100	1	10^{5}	1388.74	86.7962	7.23301
p cm	$9.80665 \cdot 10^{-3}$	$9.80665 \cdot 10^{-5}$	10^{-3}	10^{-5}	1	$1.38874 \cdot 10^{-2}$	$8.67962 \cdot 10^{-4}$	$7.23301 \cdot 10^{-5}$
oz in	$7.06155 \cdot 10^{-1}$	$7.06155 \cdot 10^{-3}$	$7.20078 \cdot 10^{-2}$	$7.20078 \cdot 10^{-4}$	72.0078	1	$6.25 \cdot 10^{-2}$	$5.20833 \cdot 10^{-3}$
in lbs	11.2985	$1.12985 \cdot 10^{-1}$	1.15212	$1.15212 \cdot 10^{-2}$	1152.12	16	1	$8.33333 \cdot 10^{-2}$
ft lbs	135.582	1.35582	13.8225	$1.38255 \cdot 10^{-1}$	13825.5	192	12	1

Conversion of inertial moments

B / A	kg cm^2	kp cm s^2	kg m^2	kp m s^2	oz in^2	oz in s^2	Lb in^2	Lb in s^2	Lb ft^2	Lb ft s^2
kg cm^2	1	$1.01972 \cdot 10^{-3}$	10^{-4}	$1.01972 \cdot 10^{-5}$	5.46748	$1.41612 \cdot 10^{-2}$	$3.41717 \cdot 10^{-1}$	$8.85075 \cdot 10^{-4}$	$2.37304 \cdot 10^{-3}$	$7.37562 \cdot 10^{-5}$
kp cm s^2	980.665	1	$9.80655 \cdot 10^{-2}$	10^{-2}	5361.76	13.8874	335.110	$8.67962 \cdot 10^{-1}$	2.32715	$7.23301 \cdot 10^{-2}$
kg m^2	10^4	10.1972	1	$1.01972 \cdot 10^{-1}$	54674.8	141.612	3417.17	8.85075	23.7304	$7.37562 \cdot 10^{-1}$
kp m s^2	98066.5	100	9.80665	1	536176	1388.74	33511.0	86.7962	232.715	7.23301
oz in^2	$1.82900 \cdot 10^{-1}$	$1.86506 \cdot 10^{-4}$	$1.82900 \cdot 10^{-5}$	$1.86506 \cdot 10^{-6}$	1	$2.59008 \cdot 10^{-3}$	$6.25 \cdot 10^{-2}$	$1.61880 \cdot 10^{-4}$	$4.34028 \cdot 10^{-4}$	$1.34900 \cdot 10^{-5}$
oz in s^2	70.6155	$7.20078 \cdot 10^{-2}$	$7.06155 \cdot 10^{-3}$	$7.20078 \cdot 10^{-4}$	386.089	1	24.1305	$6.25 \cdot 10^{-2}$	$1.67573 \cdot 10^{-1}$	$5.20833 \cdot 10^{-3}$
Lb in^2	2.92640	$2.98409 \cdot 10^{-3}$	$2.92640 \cdot 10^{-4}$	$2.98409 \cdot 10^{-5}$	16	$4.14413 \cdot 10^{-2}$	1	$2.59008 \cdot 10^{-3}$	$6.94444 \cdot 10^{-3}$	$2.15840 \cdot 10^{-4}$
Lb in s^2	1129.85	1.15212	$1.12985 \cdot 10^{-1}$	$1.15212 \cdot 10^{-2}$	6177.42	16	386.089	1	2.68117	$8.33333 \cdot 10^{-2}$
Lb ft^2	421.401	$4.29710 \cdot 10^{-1}$	$4.21401 \cdot 10^{-2}$	$4.29710 \cdot 10^{-3}$	2304.00	5.96754	144	$3.72971 \cdot 10^{-1}$	1	$3.10810 \cdot 10^{-2}$
Lb ft s^2	13558.2	13.8255	1.35582	$1.38255 \cdot 10^{-1}$	74129.0	192	4633.06	12	32.1740	1

The value of the moment of gyration GD^2 (in kp m^2) is 4 times the valueof the moment of inertia J (in kg m^2).
Example: 4 kp m^2 = 1 kg m^2

Conversion of forces

A \ B	N	kp	p	oz	lbf
N	1	$1.01972 \cdot 10^{-1}$	101.972	3.59694	$2.24809 \cdot 10^{-1}$
kp	9.80665	1	1000	35.2740	2.20462
p	$9.80665 \cdot 10^{-3}$	10^{-3}	1	$3.52740 \cdot 10^{-2}$	$2.20462 \cdot 10^{-3}$
oz	$2.78014 \cdot 10^{-1}$	$2.83495 \cdot 10^{-2}$	28.3495	1	$6.25 \cdot 10^{-2}$
lbf	4.44822	$4.53592 \cdot 10^{-1}$	453.592	16	1

Conversion of power

A \ B	kW	PS	HP	kp m/s	kcal/s
kW	1	1.35962	1.34102	101.972	$2.38846 \cdot 10^{-1}$
PS	$7.35499 \cdot 10^{-1}$	1	$9.86320 \cdot 10^{-1}$	75	$1.75671 \cdot 10^{-1}$
HP	$7.45700 \cdot 10^{-1}$	1.01387	1	76.0402	$1.78107 \cdot 10^{-1}$
kp m/s	$9.80665 \cdot 10^{-3}$	$1.33333 \cdot 10^{-2}$	$1.31509 \cdot 10^{-2}$	1	$2.34228 \cdot 10^{-3}$
kcal/s	4.1868	5.69246	5.61459	426.935	1

Conversion of pressure

A \ B	Pa	N/mm^2	bar	[kp/cm^2]	[Torr]
Pa	1	10^{-6}	10^{-5}	$1.02 \cdot 10^{-5}$	0.0075
N/mm^2	10^{6}	1	10	10.2	$7.5 \cdot 10^{3}$
bar	10^{5}	0.1	1	1.02	750
[kp/cm^2]	98100	$9.81 \cdot 10^{-2}$	0.981	1	736
[Torr]	133	$0.133 \cdot 10^{-3}$	$1.33 \cdot 10^{-3}$	$1.36 \cdot 10^{-3}$	1

1

Conversion of temperature

$$t_C = \frac{5}{9}(t_F - 32)$$

$$t_C = \frac{5}{9}(T_R - 491.67)$$

$$T_K = t_C + 273.15$$

$$T_K = \frac{5}{9} T_R$$

$$T_K = \frac{5}{9}(t_F + 459.67)$$

$$t_F = \frac{5}{9} t_C + 32$$

$$T_R = \frac{5}{9}(t_C + 491.67)$$

t_C in °C (Celsius)
t_K in K (Kelvin)
t_F in °F (Fahrenheit)
T_R in °R (Rankine)

Temperature measurement

According to the resistance of copper wire

$$\Theta_W = \frac{R_W - R_K}{R_K}(\Theta_K + 235) + \Theta_K$$

$$\Delta T = \frac{R_W - R_K}{R_K}(\Theta_K + 235)$$

Θ_W = Temperature in the warm state in °C
Θ_K = Temperature in the cold state in °C
ΔT = Excess temperature of the winding in K
R_W = Resistance in the warm state in Ω
R_K = Resistance in the cold state in Ω

Symbols for electrical and magnetic units

No.	Symbol	Meaning	SI unit	Comment
1	Q	electrical charge	C	
2	e	elementary charge	C	charge of a proton $e = 1{,}602\,177\,33 \cdot 10^{-19}$ C 1)
3	σ	surface charge density,	C/m²	
4	ϱ, ϱ_e, η	space charge density, charge density, charge/unit-volume	C/m³	ϱ_e, if P is being used for the density (mass density) or the specific electrical resistance No. 38
5	Ψ, Ψ_e	electrical flux	C	
6	D	electrical flux density	C/m²	
7	P	electrical polarisation	C/m²	$P = D - \varepsilon_0 \cdot E = x_e \cdot \varepsilon_0 \cdot E$ D as per No. 6 ε_0 as per No. 14 E as per No. 11 x_e as per No. 16
8	p, p_e	electrical dipole moment	C · m	$p = \int P \, dV$ P as per No. 7 V Volume
9	φ, φ_e	electrical potential	V	In ISO 31-5 : 1992 and IEC 27-1 : 1992 V is given as the preferred symbol, and φ as an alternative.
10	U	electrical voltage electrical potential-difference	V	As per ISO 31-5 : 1992 and IEC 27-1 : 1992 V is also permitted
11	E	electrical field strength	V/m	
12	C	electrical capacity	F	$C = Q/U$ Q as per No. 1, U as per No. 10
13	ε	Permittivity	F/m	$\varepsilon = D/E$ D as per No. 6, E as per No. 11 (previously: dielectric constant)

1

No.	Symbol	Meaning	SI unit	Comment
14	ε_0	electrical field constant	F/m	m Permittivity of free space $\varepsilon_0 = 1/(\mu_0 \cdot c_0^2)$ $= 8.854\,187\,817$ ... pF/m μ_0 as per No. 28, c_0 Speed of light
15	ε_r	relative permittivity	1	$\varepsilon_r = \varepsilon/\varepsilon_0$, (previously: relative dielectric constant) ε as per No. 13, ε_0 as per No. 14
16	x_e, x	electrical susceptibility	1	$x_e = \frac{\varepsilon - \varepsilon_0}{\varepsilon_0} = \varepsilon_r - 1$ ε as per No. 13 ε_0 as per No. 14 ε_r as per No. 15
17	I	electrical current	A	
18	J	electrical current density	A/m_2	$J = I/S$, S cross-sectional area, I as per No. 17
19	Θ	current linkage	A	
20	V, V_m	magnetic potential	A	as per ISO 31-5 : 1992 and IEC 27-1 : 1992 U_m
21	H	magnetic field strength	A/m	
22	ϕ	magnetic flux	Wb	
23	B	magnetic flux density	T	$B = \phi/S$, S S cross-sectional area, ϕ as per No. 22
24	A, A_m	magnetic vector potential	Wb/m	
25	L	inductance, self-inductance	H	
26	L_{mn}	mutual inductance	H	In ISO 31-5 : 1992 and IEC 27-1 : 1992 M is given as preferred symbol, and L_{mn} as an alternative
27	μ	permeability	H/m	$\mu = B/H$, B as per No. 23 H as per No. 21
28	μ_0	magnetic field constant	H/m	Permeability of free space $\mu_0 = 4\,\pi\,10^{-7}$ H/m $= 1.256\,637\,061\,4$ ... μH/m

No.	Symbol	Meaning	SI unit	Comment
29	μ_r	relative permeability	1	$\mu_r = \mu/\mu_0$, μ as per No. 27, μ_0 as per No. 28
30	χ_m, χ	magnetic susceptibility	1	$\chi_m = \dfrac{\mu - \mu_0}{\mu_0} = \mu_r - 1$ μ as per No. 27 μ_0 as per No. 28 μ_r as per No. 29
31	H_i, M	magnetisation	A/m	$H_i = B/\mu_0 - H = \chi_m H$ B as per No. 23 μ_0 as per No. 28 H as per No. 21 χ_m as per No. 30
32	B_i, J	magnetic polarisation	T	$J = B - \mu_0 \cdot H = \mu_0 \cdot H_i$ B as per No. 23 μ_0 as per No. 28 H as per No. 21 H_i as per No. 31
33	m	electromagnetic moment, magnetic surface moment	$A \cdot m^2$	$m = \dfrac{M}{B}$ M moment of force, torque, B as per No. 23
34	R_m	magnetic resistance, reluctance	H^{-1}	
35	Λ	magnetic permeance, permeance	H	
36	R	electrical resistance, effective resistance, resistance	Ω	
37	G	electrical conductivity, effective conductivity, conductance	S	
38	ϱ	specific electrical resistance, resistivity	Ω · m	$1\ \Omega \cdot m = 1\ \Omega \cdot m^2/m$ $= 10^6\ \Omega \cdot mm^2/m$
39	γ, σ, χ	electrical conductivity, conductivity	S/m	$\gamma = 1/\varrho$, ϱ as per No. 38 $1\ S/m = 1\ S \cdot m/m^2 = 10^{-6}\ S \cdot m/mm^2$
40	X	reactive resistance, reactance	Ω	
41	B	susceptance	S	
42	$\underline{Z}$	impedance (complex impedance)	Ω	$\underline{Z} = R + jX$2) R as per No. 36 X as per No. 40

No.	Symbol	Meaning	SI unit	Comment
43	Z, $\lvert\underline{Z}\rvert$	impedance, impedance vector	Ω	$Z = \sqrt{R^2 + X^2}$ 2) R as per No. 36 X as per No. 40
44	$\underline{Y}$	admittance (complex admittance)	S	$\underline{Y} = 1/\underline{Z} = G + \mathrm{j}B$ 2) B as per No. 41 G as per No. 37 $\underline{Z}$ as per No. 42
45	Y, $\lvert\underline{Y}\rvert$	admittance, admittance vector	S	$Y = \sqrt{G^2 + B^2}$ 2) B as per No. 41 G as per No. 37
46	Z_w, Γ	characteristic impedance	Ω	
47	Z_0, Γ_0	intrinsic impedance of free space	Ω	$Z_0 = \sqrt{\mu_0/\varepsilon_0} = \mu_0 \cdot c_0 = \frac{1}{\varepsilon_0 \cdot c_0}$ $\approx 376.730\,313 \ldots$ Ω μ_0 as per No. 28, c_0 speed of light, ε_0 as per No. 14
48	W	energy, work	J	
49	P, P_p	effective power	W	
50	Q, P_q	reactive power	W	unit also as var
51	S, P_s	apparent power	W	see DIN 40110 unit also VA As for impedance, a distinction must be made between the complex apparent power and its vector value (see Nr. 42 and Nr. 43)
52	S	electromagnetic energy flow density, electro-magnetic power density, Poynting vector	W/m^2	$S = E \times H$ E as per No. 11 H as per No. 21
53	$\varphi(t)$	phase angle 2)	rad	t time, time period, duration
54	φ	phase-shift angle 2)	rad	also vector angle of an impedance $\underline{Z} = Z \cdot e^{j\varphi}$, $\underline{Z}$ as per No. 42, Z as per No. 43
55	δ_ε	permittivity loss-angle	rad	
56	δ_μ	permeability loss-angle	rad	
57	λ	power factor	1	$\lambda = P/S$ P as per No. 49, S as per No. 51, $\lambda = \cos\varphi$ 2), φ as per No. 54

No.	Symbol	Meaning	SI unit	Comment
58	d	loss factor	1	$d = P/\|Q\|$ P as per No. 49, Q as per No. 50, $d = \tan \delta$ [2]), δ as per No. 55 or Nr. 56
59	δ	penetration, equivalent conductive thickness	m	
60	g	fundamental level	1	
61	k	harmonic level, distortion factor	1	
62	F	form factor	1	
63	m	number of phases	1	
64	N	number of turns	1	
65	k	coupling factor	1	$k = L_{12}/\sqrt{L_1 \cdot L_2}$ L as per No. 25, L_{12} as per No. 26

1) The uncertainty given for the last figures indicates the standard deviation.

2) Valid only for sinusoidal current and voltage waveforms.

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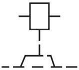
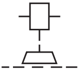
1

Electrical circuit symbols

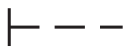
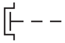
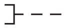
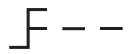
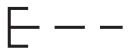
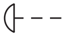
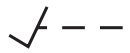
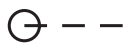
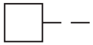
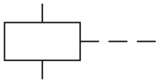
2

Circuit symbols
DIN EN 60617

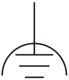
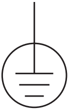
Control elements

Circuit Symbol	Description
	Notch Not self-release Device to hold a given position
	Lock-out, non-latching
	Lock-out latching
	Coupling, free
  	Brake Examples: Electromagnetically activated brake Electromagnetically released brake

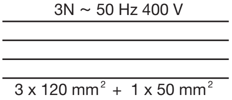
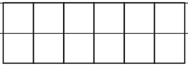
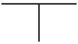
Controller/regulator

Circuit Symbol	Description
	Manual operation, general
	Manual operation with limited access
	Operation by pulling
	Operation by rotating
	Operation by pressing
	Emergency-off switch, “mushroom” type
	Operation by handwheel
	Operation by pedal
	Operation by detachable handle
	Operation by roller
	Generalized power drive Operation by stored mechanical energy. Information that shows the type of stored energy that can be entered in the rectangle.
	Tripped by electromechanical ef-fect

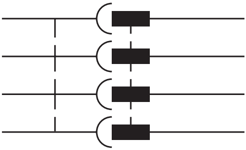
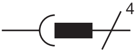
Earth and ground connectors, equipotential bonding

Circuit	Symbol	Description
		Generalized earth Additional details must be added to define the type or purpose of the earth
		Low-noise earth
		Protective earth Protective earth connection This symbol may be used instead of  to designate an earth connection that performs a defined protective function, e.g. for protection from electrical shock in a fault condition.
		Ground Housing The hatching can be omitted if no ambiguity is caused. The line that represents the housing must then be made thicker: 

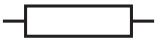
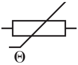
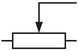
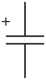
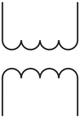
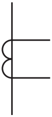
Connections

Circuit Symbol	Description
	3-pole connection Additional information may be attached as follows: – type of current – type of supply – frequency – voltage – number of conductors – cross-section of individual conductors – chem. symbol for cond. material The number of conductors is followed by an “x” and then the cross-section. If there are different cross-sections the details should be separated by a “+” sign.
 	3-phase 4-wire system with three phases and a neutral conductor, 50 Hz, 400 V, outer conductor 120 mm^2, neutral conductor 50 mm^2 3 N can be replaced by 3+N.
	Flexible connection
	Shielded conductor
	Connection (e. g. terminal)
	Connector strip Connector designations can be provided.
	T-connection The symbol  is shown with the interconnection point

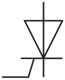
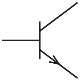
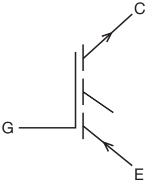
Connectors

Circuit Symbol	Description
	Plug/socket, all-pole representation
	Plug/socket, multi-pole

Passive components

Circuit Symbol	Description
	Generalized resistor Generalized attenuator
	Resistor, temperature-dependent
	Resistor with movable (slider) contact Potentiometer
	Generalized capacitor
	Polarized capacitor e.g. electrolytic capacitor
	Inductance Coil Winding Choke
	Inductance with magnetic core
	Transformer
	Current transformer

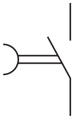
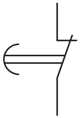
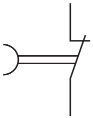
Semiconductors

Circuit Symbol	Description
	Diode
	Avalanche diode, unidirectional Voltage-limiter diode Z-diode
	Reverse-blocking thyristor, P-gate (cathode-controlled)
	NPN-transistor
	Insulated-gate bipolar transistor (IGBT), enhancement type, P-channel

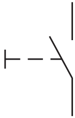
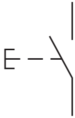
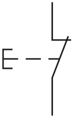
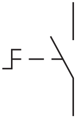
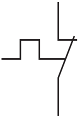
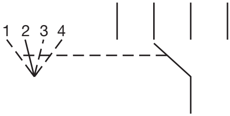
Contacts

Circuit Symbol	Description
	Closer
	Opener
	Changeover with make-after-break
	Passing contact on activation
	Passing contact on release
	Closer (in a set of contacts) that makes before the other contacts in the set Leading closer/make contact

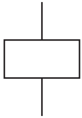
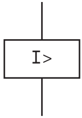
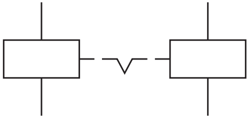
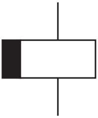
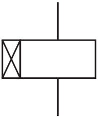
2

Circuit Symbol	Description
	Opener (in a set of contacts) that opens after the other contacts in the set Trailing opener
	Closer, delayed make, when the equipment of which it is part is activated Delayed-action opener
	Closer, delayed break, when the equipment of which it is part is de-activated Delayed-released closer
	Opener, delayed break, when the equipment of which it is part is activated Delayed-action opener
	Opener, delayed break, when the equipment of which it is part is activated Delayed-action opener

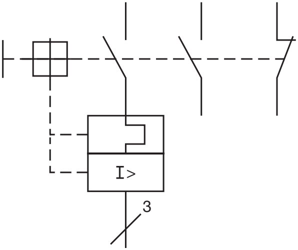
Switches

Circuit Symbol	Description
	Generalized manually operated switch
	Pressure switch, closer with automatic release
	Pressure switch, opener with automatic release
	Pressure switch, closer without automatic release
	Opener with automatic thermal activation (thermostat, e.g. bimetal)
	Multistage switch

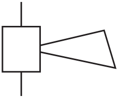
Relays

Circuit Symbol	Description
	Electromechanical actuation, generalized Relay coil, generalized
	Overcurrent relay
	Locking relay
	Electromechanical actuation with delayed release
	Electromechanical actuation with delayed activation

Protective device

Circuit Symbol	Description
	Generalized fuse
	Motor cut-out

Lamps and signalling devices

Circuit Symbol	Description
	Generalized lamp Generalized indicator
	Horn Klaxon

Design letters to identify the type of equipment

Equipment that is not included in the examples must be assigned to the appropriate category. Functional features are more important here than the assembly.

Designation letter	Type of equipment	Examples
A	Modules, sub-assemblies	Amplifiers with valves or transistors, magnetic amplifiers, lasers, masters *Equipment combinations; modules and sub-assemblies that form an assembly, but cannot be clearly assigned to another designated letter such as plug-in modules, frames, inserts, plug-in cards, pcb assemblies, local controls etc.*
B	Transducers from non-electrical to electrical variables or the reverse	Thermo-electric sensors, thermal cells, photo-electric cells, dynamometers, quartz-crystal transducers, microphones, phono pickups or loudspeakers, synchro-transmitters, tracking potentiometers *Transducers, thermocouples, resistance thermometers, photo-sensitive resistors, load cells, strain cells, strain gauges, piezo-electric transducers, speed sensors, pulse transmitters, tachometers, angle/path transmitters, proximity detectors, Hall effects sensors, magnetoresistive potentiometers, transmitters for: pressure, density, level, temperature*
C	Condensers	
D	Binary elements, propagation conductor, storage devices	Digital integrated circuit and components, propagation conductor, bistable devices, monostable devices, registers core stores, registers, magnetic tape equipment, disk storage *Devices for logic and digital control, computing technology. Integrated circuits with logic and digital functions, delay elements, signal gate, timing circuits, storage and memory functions, e.g. drum and tape stores, shift registers, logical components such as AND and OR elements.* *Digital equipment, pulse counters, digital controllers and calculators*

Designation letter	Type of equipment	Example
E	Various	Lightning equipment, heating equipment, equipment not otherwise covered by this list *Electrical filters, electrical fences, fans, protection of measuring equipment, reservoirs*
F	Protective devices	Fuses, overvoltage discharge devices, overvoltage deviation device *Telephone line circuit breakers, relay cut-outs, bimetallic cut-out, magnetic cut-out, pressure switches, air-vane relays, Buchholz relay, electronic device for signal monitoring, signal, cable, function monitoring; installation cable breakers*
G	Generators, power	Rotary generators, rotary converters, power supply equipments batteries, oscillator, quartz oscillator *static generator and converters; charging equipment, PSUs, inverters, clock generators*
H	Signalling devices	Optical and acoustic signalling equipment *Signal lamps; devices for hazard and time signals, time-sequence signal device, movements recording equipment, drop indicator relay*
J		free
K	Relays, contactors	*Power contactors, auxiliary; auxiliary relays, time relays, blinker relays and Reed relays*
L	Inductances	Induction pulse, waves traps, inductors (parallel and in series)
M	Motors	
N	Analog components	operational amplifier, hybrid Analog/Digital components
P	Measuring and test equipment	Display, recording and counting measuring equipment, pulse generator, clocks *Analog, logic and digital display and recording measuring equipment (Indicators, recorders, counters), mechanical counters, logic-state indicators, oscillographs, video display, simulators, test adaptors, measurement/test/supply point*

Designation letter	Type of equipment	Example
Q	Power switching-devices	Power switches, isolating switches *switches in power circuitry, switches with protective devices, high-speed circuit breakers, load disconnector, star delta switches, polarity-reversal switch, drum starter, disconnecting links, cell switch, fuse disconnector, fuse-switch disconnector, installation switch, motor circuit-breaker*
R	Resistors	adjustable resistors, potentiometers, rheostat, shunt resistors, heat conductors *Fixed-value resistor, starter resistors, brake resistors, cold conductors, measuring resistors, shunt*
S	Switches, selectors	Control switches, pushbuttons, limit switches, selectors, diallers, coupled step switches *Control equipment, control units, built-in units, pushbuttons, toggles switches, illuminated switches, control-discrepancy switches, measuring points switches, drum controllers, cam controllers, decade switches, code switches, function keys, dial selectors, rotary switches*
T	Transformers	Voltage transformer, current transformer *Mains, isolating, and control-power transformers*
U	Modulators, converters *of electrical variables*	Discriminator, demodulator, frequency converter, encoding/decoding devices, inverter, converters, telegraph modulators demodulator *frequency modulators and demodulators to current/voltage converter, analog digital converters; digital analog converter, signal isolators, DC-current and DC-voltage converters, parallel-serial and serial-parallel-converters; encoders/decoders, optocouplers, remote control devices*
V	Valve (tubes), semiconductor	Electrical valves, gas-discharge valves, diodes, transistors, thyristors *Display tube, amplifier valves, thyratrons, mercury rectifier, Zener diodes, tunnel diodes, varicap diodes, triacs*
W	Transmission ans, waveguide	Jumper wires, cables, busbars, waveguide, directional me-waveguide, waveguides/directional couplers, dipoles,

Designation letter	Antenna Type of equipment	*light pipes, coaxial cables, TFH-, UKW directional transmission and HF-cable transmission, telephone lines* Example
X	Clamps, plugs, sockets	Plugs and sockets, clips, test connectors, socket terminal strips, solder tag strips, bridges, cable connectors and cable sockets *Coax-connector; sockets; measuring sockets; multi-pin connectors; distributor boards; cable connectors; programming connectors; crossed distributor boards; latch*
Y	Electrically operated interlocks	Brakes, couplings, compressed-air solenoid *Local drive, lifting appliance; brake release, control drive, safety magnets, mechanical locks, motor potentiometer, Permanent-magnets, Teletype, electrical typewriter, printers, plotters, console typewriter*
Z	Termination, hybrid transfomer, filters, zers, limiters *adaptation devices, splitters*	cable simulation, level controls, crystal filters, networks equali- *R/C and L/C-filters, spark suppressors, active filters,high-pass low-pass and bandpass filters, frequency divider, damping elements*
NOTE 1: In IEC 60 617-1 general index: 1985 "Graphical symbols for diagrams – Part 1: General information, general index. Cross-reference tables" are designated letters mostly used for equipment with standard circuits NOTE 2: If more than one designation can be given, because a piece of equipment can be described with more than one name, one should use the version that occurs most.		

2

Identification keys for equipment and conductors
DIN EN 60445
DIN EN 60617

Specified conductor	Designation of the equipment	Designation of the cable ends	Symbol as per DIN EN 60617
AC-supply network conductors Phase 1 Phase 2 Phase 3 Neutral conductor	 U V W N	 L1 L2 L3 N	
DC-supply network conductors Positive Negative Middle conductor	 C D M	 L+ L- M	
Protective earth	PE	PE	
PEN-conductor	–	PEN	
Earth conductor	E	E	
Low-noise earth	TE	TE	
Ground connection	MM1)	MM1)	
Equipotential connection	CC1)	CC1)	

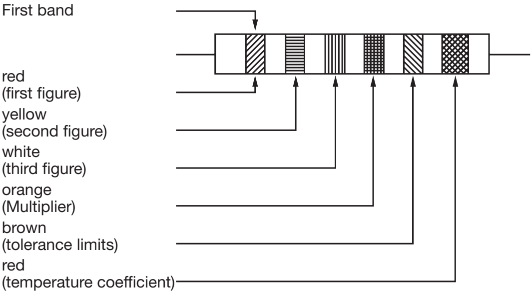
1) This designation is only valid if these connections or conductors are not intended to be used for the earth or protective earth.

Colour of resistors DIN EN 60062

Colour coding

Code-colour name	Resistance value in Ω Figure	Multiplier	Tolerance of the resistance value	Temperature coefficient (10^{-6}/°C)
none	–	–	± 20 %	–
silver	–	10^{-2}	± 10 %	–
gold	–	10^{-1}	± 5 %	–
black	0	1	–	± 250
brown	1	10	± 1 %	± 100
red	2	10^2	± 2 %	± 50
orange	3	10^3	± 0.05 %	± 15
yellow	4	10^4	–	± 25
green	5	10^5	± 0.5 %	± 20
blue	6	10^6	± 0.25 %	± 10
violet	7	10^7	± 0.1 %	± 5
grey	8	10^8	–	± 1
white	9	10^9	–	–

Example for colour coding of resistance values with three bands for figures and temperature coefficient. Resistance 249 kΩ, tolerance limits ± 1 %, temperature coefficient ± 50 · 10^{-6}/°C.



2

Drive dimensioning

Physical equations for drive technology

Translation	Rotation	
$s = v \cdot t$	path or angle	$\varphi = \omega t$
$v = \frac{s}{t}$	speed (velocity)	$v = d\pi n = \omega r$
	angular velocity	$\omega = \dot{\varphi} = 2\pi n = \frac{v}{r}$
$a = \frac{v}{t}$	acceleration	$\dot{\omega} = \ddot{\varphi} = \frac{\omega}{t}$
$F = m \cdot a$	accelerating force -torque	$M = J \cdot \dot{\omega}$
	torque	$M = F \cdot r$
$P = F \cdot v$	power	$P = M \cdot \omega$
$W = F \cdot s$	energy	$W = M \cdot \varphi$
$W = \frac{1}{2} m v^2$	energy	$W = \frac{1}{2} J \omega^2$

Important definitions

$1\ N = 1\ kg \frac{m}{s^2}$	force
$1\ kp = 9.81\ N$	force
$1\ PS = 75\ kp \frac{m}{s} = 0.7355\ kW$	power
$1\ Ws = 1\ Nm = 1\ J$	work, energy
$1\ kg\ m^2 = 1\ Ws^3 = 1\ Nms^2$	moment of inertia
$g = 9.81\ m/s^2$	acceleration due to gravity

Dimensional equations (see P. 47 for units)

speed (velocity) $v = \frac{d \cdot \pi \cdot n}{1000}$

force $F = 1000 \frac{M}{r} = \mu \cdot m \cdot g$

torque $M = \frac{F \cdot r}{1000}$

$M = \frac{3 \cdot 10^4\ P}{\pi \cdot n} = \frac{9549\ P}{n}$

work $W = F \cdot s = m \cdot g \cdot s$

kinetic energy $W = \frac{m\ v^2}{7200}$

rot. energy $W = \frac{\pi^2}{1800} J\ n^2 = \frac{J\ n^2}{182{,}4}$

power

rotation $P = \frac{\pi}{30} \cdot 10^{-3}\ M \cdot n = \frac{M \cdot n}{9549}$

translation $P = \frac{F \cdot v}{6 \cdot 10^4}$

hoist $P = \frac{m \cdot g \cdot v}{6 \cdot 10^4}$

pump $P = \frac{V \cdot p}{1000}$

Important definitions

$\eta = \frac{P_{ab}}{P_{zu}}$ efficiency

$i = \frac{n_1}{n_2} = \frac{M_2}{M_1}$ gear ratio

3

Acceleration of drives

3

torque motor-mode

$$M = M_L + M_a + M_v = \left(M_L + \frac{\pi}{30} \cdot J \frac{\Delta n}{t_a}\right) \cdot \frac{1}{\eta}$$

torque generator-mode

$$M = M_L - M_a - M_v = \left(M_L - \frac{\pi}{30} \cdot J \frac{\Delta n}{t_a}\right) - \frac{M_L}{\eta}$$

acceleration torque

$$M_a = \frac{\pi}{30} J \frac{\Delta n}{t_a} = 0{,}105\, J \frac{\Delta n}{t_a}$$

taking into account

$$n = \frac{1000\, v}{d \cdot \pi}$$

$$M_a = \frac{100}{3d} J \frac{\Delta v}{t_a}$$

work, energy

$$W = \frac{\pi^2}{1800} J\, \Delta n^2 \frac{M}{M - M_L} = \frac{J \Delta n^2\, M}{182.4\, (M - M_L)}$$

$$W = \frac{5000}{9} J \frac{\Delta v^2}{d^2} \frac{M}{M - M_L}$$

total power

$$P = P_L + P_a$$

power at load

$$P_L = \frac{\pi \cdot n \cdot M_L}{3 \cdot 10^4} = \frac{n \cdot M_L}{9549} = \frac{v \cdot M_L}{30 \cdot d}$$

acceleration power with M = constant

$$P_a = \frac{\pi^2 n}{9 \cdot 10^5} J \frac{\Delta n}{t_a} = \frac{n\, J\, \Delta n}{9{,}12 \cdot 10^4 \cdot t_a}$$

$$P_a = \frac{10\, v}{9d^2} J \frac{\Delta v}{t_a} = \frac{m \cdot v \cdot \Delta v}{3{,}6 \cdot 10^6\, t_a}$$

The sign of Δn and M_a reverses on braking.

acceleration time

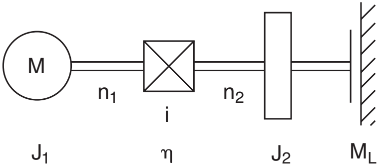
$$t_a = \frac{\pi}{30}\, J\, \frac{\Delta n}{M - M_L} = 0.105\, \frac{J\Delta n}{M - M_L} = \frac{100J}{3d}\, \frac{\Delta v}{M - M_L}$$

$$t_a = \frac{\pi^2 n\, J\Delta n}{9 \cdot 10^5\, (P - P_L)} = \frac{n\, J\Delta n}{9.12 \cdot 10^4\, (P - P_L)}$$

traversing drive with acceleration $P = \frac{m\, v}{6 \cdot 10^4} \left(\mu \cdot g + \frac{\Delta v}{60\, t_a} \right)$

M = motor torque in Nm
M_L = load torque in Nm
M_a = acceleration torque in Nm
P = motor power in kW
P_L = power at load in kW
P_a = acceleration power in kW
n = speed in rpm
Δn = speed difference in rpm
v = velocity in m/min
Δv = velocity difference in m/min
J = total moment of inertia in kgm^2
m = mass in kg
F = force in N
W = energy in J
t_a = acceleration time in s
s = distance in m
d = diameter in mm
r = radius in mm
μ = coefficient of friction
V = pumping volume in m^3/s
p = pressure in N/m^2
g = 9.81 m/s^2
π = 3.14
η = gearing (gearbox) efficiency

Optimum acceleration



3

1. Generalized accelerating drive

wanted: transmission ratio i, motor speed n_1 and mot. power P_1

$$P_1 = \frac{\pi n_2 M_L}{30\eta} + \frac{\pi^2}{900 t_a}\left(J_1 n_1^2 + J_2 n_2^2\right)$$

$$n_{1\ opt} = \sqrt{\frac{n_2}{J_1}\left(\frac{30 \cdot M_L}{\pi \cdot \eta}\, t_a + \frac{n_2 J_2}{\eta}\right)}$$

Simplified: with $M_L = 0$; $\eta = 1$

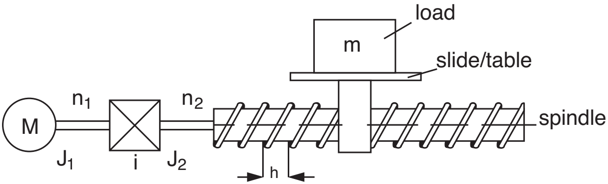
$$i = \frac{n_1}{n_2}$$

$$i_{opt} = \sqrt{\frac{J_2}{J_1}}$$

i = transmission ratio
i_{opt} = transmission ratio for optimum dynamics
n = speed in rpm
t_a = acceleration time in s
M_L = load torque in Nm
J_2 = load moment of inertia in kgm^2
J_1 = motor moment of inertia in kgm^2
P_1 = motor power in W
η = efficiency of the gearing

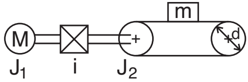
Optimum acceleration

1.1. translation (traversing, linear)



$$J_2 = m \left(\frac{h}{2000\pi}\right)^2$$

1.2. rotational



$$J_2 = m \left(\frac{d}{2000}\right)^2$$

n = speed in rpm
i = gear ratio
J_2 = load moment of inertia in kgm^2, derived from translation (traversing, linear)
J_1 = motor moment of inertia in kgm^2, derived from rotational
m = mass in kg
h = leadscrew pitch in mm
d = roller diameter in mm

Moments of inertia

solid cylinder	hollow cylinder
$J = \frac{m}{2} r^2 = \frac{\pi}{2} l \varrho r^4$	$J = \frac{m}{2} (r_a^2 + r_i^2) = \frac{\pi}{2} l \varrho \, (r_a^4 - r_i^4)$

3

numerical equations for steel with a density $\varrho = 7.85$ g/cm^3

J = moment of inertia in kg cm^2

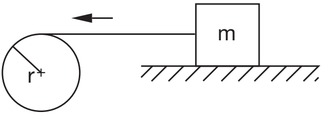
m = mass in kg

d = diameter in mm

l = length in mm

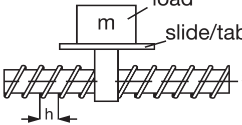
$J = \frac{m\,d^2}{800}$	$J = \frac{m}{800} (d_a^2 + d_i^2)$
$J = 7.7 \cdot 10^{-9} d^4 l$	$J = 7.7 \cdot 10^{-9} (d_a^4 - d_i^4) \cdot l$

Movement by transport rollers (generalized)



$$J = m\, r^2$$

Movement by leadscrews (generalized)

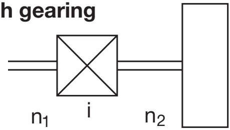


$$J = m \left(\frac{h}{2\,\pi}\right)^2$$

conversion from linear to rotary motion

$$J = \frac{m}{4\,\pi^2} \left(\frac{v}{n}\right)^2 = \frac{m}{39.5} \left(\frac{v}{n}\right)^2$$

reduction through gearing



$i = \dfrac{n_1}{n_2}$

$J_1 = \dfrac{J_2}{i^2}$

J = moment of inertia in kg m^2

m = mass in kg

v = velocity in m/min

n = speed in rpm

3

Angle of rotation as a function of torque for hollow and solid shafts

Generally valid is $$M = \frac{\pi G \varphi}{180\, l} J_p$$

$$J_p = \frac{\pi}{32} (D^4 - d^4)$$

3

M = torque
G = modulus of rigidity 80 000 N/mm²
φ = torsional angle in degrees
l = shaft length
D = external diameter
d = internal diameter
J_p = polar moment of inertia

Dimensions		Polar Inertial torque	Weight per m	Inertial torque per m	Torque in Nm at torsion for l = 1 m and φ				
D mm	d mm	Jp cm⁴	G kg	J kg cm²	0.25°	0.5°	0.75°	1°	1.25°
10	–	0.098	0.62	0.077	0.34	0.69	1.03	1.37	1.71
15	–	0.50	1.39	0.39	1.73	3.47	5.20	6.94	8.67
20	–	1.57	2.47	1.23	5.48	11.0	16.4	21.9	27.4
25	–	3.83	3.85	3.01	13.4	26.8	40.2	53.5	66.9
30	–	7.95	5.55	6.25	27.8	55.5	83.3	111	139
40	–	25.1	9.86	19.7	87.7	175	263	351	439
50	–	61.4	15.4	48.2	214	428	643	857	1070
35	30	6.78	2.00	5.32	23.7	47.3	71.0	94.7	118
38	30	12.5	3.35	9.83	43.7	87.4	131	175	218
40	30	17.2	4.32	13.5	60.0	120	180	240	300
45	40	15.1	2.62	11.9	52.8	106	158	211	264
50	40	36.2	5.55	28.4	126	253	379	506	632

Coefficients of friction (average values):

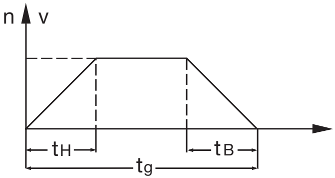
No.	Materials of the frictional surfaces	μ (static friction)			μ (dynamic friction)		
		dry	lubri-cated	with water	dry	lubri-cated	with water
1	steel on steel	0.15	0.1	–	0.1	0.05	–
2	steel on cast-iron, gunmetal or bronze	0.2	0.1	–	0.16	0.05	–
3	metal on wood	0.6-0.5	0.1	–	0.5-0.2	0.08-0.02	0.26-0.22
4	wood on wood	0.65	0.2	0.7	0.4-0.2	0.16-0.04	0.25
5	leather on metal (seals)	0.6	0.25	0.62	0.25	0.12	0.36
	leather belts on cast-iron	0.5-0.6	–	0.36	0.28	0.12	0.38
7	leather belts on wood	0.47	–	–	0.27	–	–

Frictional coefficients for brake pads

Motional resistance coefficient μ for various vehicles

Vehicle	Motional resistance coefficient μr
railway wagons	0.0025
tramcars with ball/roller bearings	0.005
tramcars with journal bearings	0.018
mining trolleys	0.01
road vehicle on asphalt	0.01
road vehicle on cobbles	0.04
road vehicle on unsurfaced road	0.05 … 0.15
road vehicles (rubber on asphalt)	0.02 … 0.03
aerial ropeway, funicular	0.007 … 0.017

Positioning drive



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v = velocity in m/min	v = velocity in m/s
$v = \frac{d \cdot \pi \cdot n}{1000}$	$v = \frac{d \cdot \pi \cdot n}{6 \cdot 10^4}$
$S_H = \frac{v \cdot t_H}{0.12}$ $S_B = \frac{v \cdot t_B}{0.12}$	$S_H = 500v \cdot t_H$ $S_B = 500v \cdot t_B$
$s = \frac{v}{0.12} (2 \cdot t_g - t_H - t_B)$	$s = 500v (2t_g - t_H - t_B)$
$U_B = \frac{t_B\, n}{120} = \frac{t_B\, v}{0.12\, d \cdot \pi}$	$U_B = \frac{t_B \cdot n}{120} = 500\, \frac{t_B \cdot v}{d \cdot \pi}$

n = speed in rpm
s = total feed distance in mm
S_H = acceleration distance in mm
S_B = braking distance in mm
d = roller diameter in mm
t_H = acceleration time in s
t_B = braking time in s
t_g = total feed/traversing time in s
U_B = no. of turns for braking

Dimensioning of winder drives

Winding ratio: $q = \frac{d_{max}}{d_{min}}$

Speed in rpm: $n = \frac{1000\ v}{d \cdot \pi}$

3

Torque in Nm: $M = \frac{F \cdot d}{2000}$

Winder power in kW: $P_W = \frac{F \cdot v}{6 \cdot 10^4}$

Gear ratio to convert the motor speed to the bobbin speed $i = \frac{\pi \cdot d_{min} \cdot n_m}{1000\ v}$

Acceleration torque in Nm:

$$M_a = \frac{100 \cdot \Delta v}{3d\ t_a} \left[J_R + \frac{m}{8 \cdot 10^6} (d^2 + d_{min}^2) \right]$$

$$m = \frac{\pi\ b\ \varrho}{4 \cdot 10^6} (d^2 - d_{min}^2)$$

Spec. weight ϱ in kg/dm^3

Acceleration power in kW:

$$P_a = \frac{10 \cdot v \cdot \Delta v}{9\ d^2\ t_a} \left[J_R + \frac{m}{8 \cdot 10^6} (d^2 + d_{min}^2) \right]$$

Packing characteristics of the winding

flat material	round material
$L = \frac{\pi}{4000\,S}\left(d^2_{max} - d^2_{min}\right)$	$\frac{\pi\,b}{2000\sqrt{3}\;d_s^2}\left(d^2_{max} - d^2_{min}\right)$
$d_{max} = \sqrt{\frac{4000}{\pi}\,L \cdot S + d^2_{min}}$	$\sqrt{\frac{2000\sqrt{3}\cdot L \cdot d_s^2}{\pi\,b} + d^2_{min}}$
$L_m = \frac{\pi\,d^2_{max}}{4000\,S}$	$\frac{\pi\,b\,d^2_{max}}{2000\sqrt{3}\;d^2_s}$

generalized $$L = L_m\left(1 - \frac{1}{q^2}\right)$$

relative packing length in %

q	2	3	4	5	6	7	8	9	10
$\frac{L}{L_m}\,100$	75.0	88.9	93.8	96.0	97.2	98.0	98.4	98.8	99.0

winding time in s: $$t = 60\,\frac{L}{v}$$

torque = f (t) $$M = \frac{F}{2000}\sqrt{d^2_{min} + \frac{200}{3\,\pi}\,Svt}$$

torque = f (t) $$n = \frac{1000\,v}{\pi\sqrt{d^2_{min} + \frac{200}{3\,\pi}\,Svt}}$$

diameter = f (t) $$d = \sqrt{d^2_{min} + \frac{200}{3\,\pi}\,Svt}$$

3

Explanation of winder dimensioning

d	= diameter in mm
d_{min}	= bobbin diameter in mm
d_{max}	= max. winding diameter in mm
S	= material thickness in mm
d_s	= material diameter in mm
b	= winding width in mm
i	= gear ratio
L	= length of material in m
L_m	= max. possible winding length in m
n	= speed in rpm
n_B	= speed for calculation in rpm
n_m	= max. speed in rpm
n_N	= rated motor speed in rpm
n_O	= synchronous speed in rpm
V	= velocity in m/min
Δv	= speed difference in m/min
t	= winding time in s
t_a	= acceleration time in s
F	= tension in N
M	= torque in Nm
M_a	= acceleration torque in Nm
J_R	= moment of inertia of the unchanging portion of the bobbin, in kgm²
m	= mass in kg
q	= winding ratio
p	= no. of poles
P	= requ. motor power in kW
P_N	= rated motor power in kW
P_a	= acceleration power in kW
P_E	= base power in kW (calculation aid)
P_W	= winder power in kW
η	= mech. efficiency of the gearing

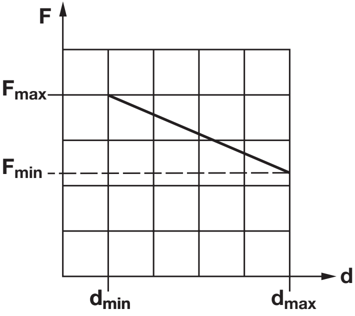
To be able to dimension the motor to be just as large as is required, it is necessary to know how the tension varies with the diameter.

$$\frac{F_{max}}{F_{min}} \leqq q:$$

$$P = \frac{v \cdot F_{min} \cdot q}{6 \cdot 10^4 \cdot \eta}$$

$$\frac{F_{max}}{F_{min}} > q:$$

$$P = \frac{v \cdot F_{max}}{6 \cdot 10^4 \cdot \eta}$$



Gearbox dimensioning for winder drives

The gear ratio i can be chosen between the limits of i_a and i_b.

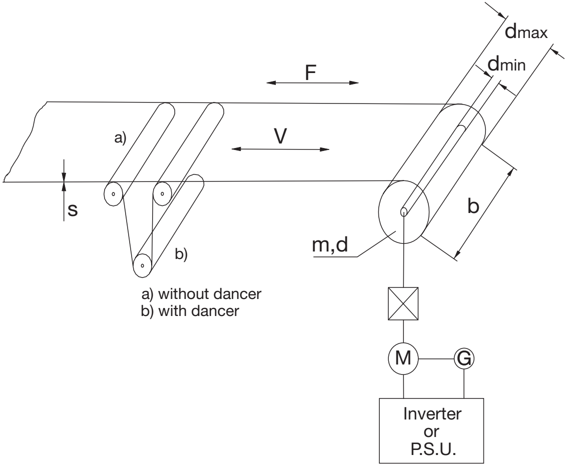
lower limit: $$i_a = \frac{\pi \cdot d_{min} \cdot n_N \cdot P}{1000 \cdot v \cdot P_N}$$

upper limit: $$i_b = \frac{\pi \cdot d_{min} \cdot n_N}{1000 \cdot v}$$

After deciding on the gear ratio, the data should be checked:

$$n_{min} = \frac{1000 \cdot i \cdot v}{\pi \cdot d_{max}} \qquad F_{min} = 6 \cdot 10^4 \, \eta \, \frac{P_N \, n_{min}}{V \, n_N}$$

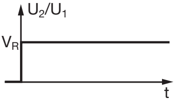
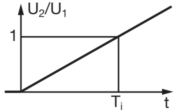
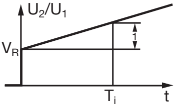
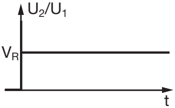
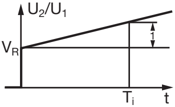
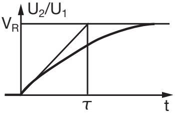
$$n_{max} = q \cdot n_{min} \qquad F_{max} = q \cdot F_{min}$$



a) without dancer
b) with dancer

Control loops

Switching of Amplifiers

Control loop response	Transfer function	Frequency behaviour
P		$F_R = V_R$
I		$F_R = \frac{1}{pT_i}$
PI		$F_R = V_R \frac{1 + pT_n}{pT_n}$
PD		$F_R = V_R\,(1 + pT_v)$
PID		$F_R =$ $V_R \frac{(1 + pT_n)\,(1 + pT_v)}{pT_n}$
active low-pass		$F_R = \frac{V_R}{1 + p\tau}$

Optimum dimensioning and the effects

Controller setting	Effect
P-component larger	Speed reacts very sharply to setpoint changes
P-component too small	Unstable speed, transient is too long
I-component too large	Soft control loop response, large overshoot
D-component larger	Overshoot is damped Speed range is stable.
D-component too large	Rough running, irregular speed

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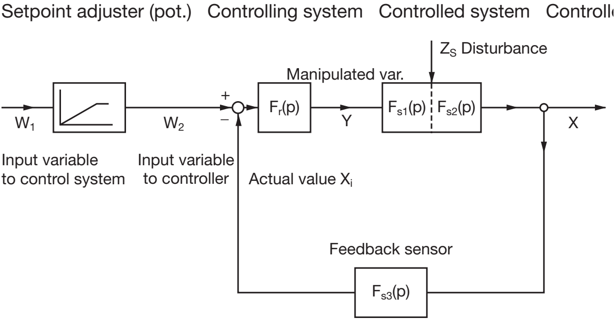
Important terms in control technology
Control loop



Frequency response within the control loop

open control loop: $F_o(p) = F_r(p) \cdot F_s(p)$

controlled system: $F_s(p) = F_{s1}(p) \cdot F_{s2}(p)$

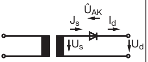
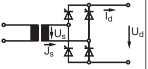
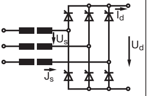
feedback: $F_{s3}(p) = \dfrac{x_i(p)}{x\,(p)}$

Closed control loop

as a function of the control input variable W_2: $F_w(p) = \dfrac{x\,(p)}{W_2(p)} = \dfrac{F_o(p)}{1 + F_o(p) \cdot F_{s3}(p)}$

as a function of the disturbance variable Zs: (additive disturbance) $F_z(p) = \dfrac{x\,(p)}{Z_s(p)} = \dfrac{F_w(p)}{F_r(p) \cdot F_{s1}(p)}$

$F_z(p) = \dfrac{x\,(p)}{Z_s(p)} = \dfrac{F_{s2}(p)}{1 + F_o(p) \cdot F_{s3}(p)}$

	Inverter circuits	Trfr.	Recti- volt- age	PIV curr. age	Trfr.	Ripple char.	Control
	Explanations overleaf		$\frac{U_{di}}{U_S}$	$\frac{\hat{U}_{AK}}{U_S}$	$\frac{J_S}{I_d}$	w_u	$\frac{U_d}{U_{di}}$
Half-wave rect.	E1  	||	0.45 $\frac{\sqrt{2}}{\pi}$	2.83 $2\sqrt{2}$	1.41 $\sqrt{2}$	1.21	1 pulse
Full-wave rectifier	B2  	||	0.90 $\frac{2}{\pi}\sqrt{2}$	1.41 $\sqrt{2}$	1 1	0.485	2 pulse
						full-wave	$\cos\alpha$
						half-wave	$\frac{1+\cos\alpha}{2}$
	B6  		1.35 $\frac{3\sqrt{2}}{\pi}$	1.41 $\sqrt{2}$	0.816 $\sqrt{\frac{2}{3}}$	0.042	6 pulse
						full-wave	$\cos\alpha$
						half-wave	$\frac{1+\cos\alpha}{2}$

Form factor

$$F_F = \frac{J_{eff}}{I_d} = \sqrt{1 + w_i^2}$$

F_F = form factor

J_{eff} = value of current in A

J_s = value of current in A

I_d = average DC value in A

U_s = supply voltage in V

U_d = DC voltage in V

U_{di} = theoretical DC voltage in V

Ripple

$w_i = \sqrt{F_F^2 - 1}$ current

$w_u = \dfrac{\sqrt{\sum U_{\nu i}^2}}{IJ_d}$ voltage

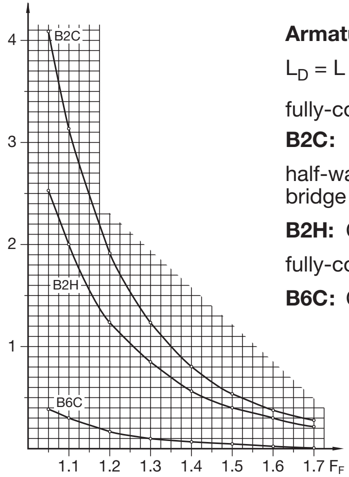
$\hat{U}_{AK}$ = p.i.v. of the switching device in V

$U_{\nu i}$ = r.m.s. value of ν-ten harmonic in V

L_A = Inductance of the armature in mH

L_D = Inductance of the armature choke in mH

L = total inductance required in mH



Armature choke

$$L_D = L - L_A = C\frac{U_s}{I_d} - L_A$$

fully-controlled single-phase bridge

B2C: $C = 5.4 \cdot F_F^{-5.67}$

half-wave controlled single-phase bridge

B2H: $C = 3.24 \cdot F_F^{-5.07}$

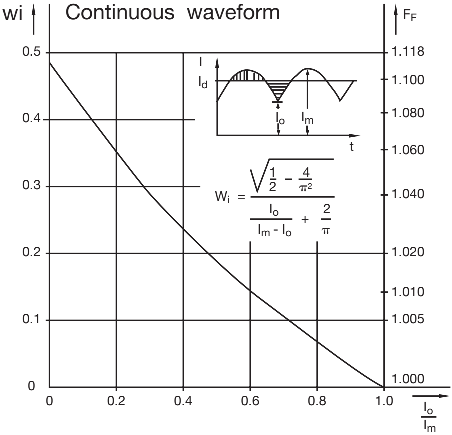
fully-controlled 3-phase bridge

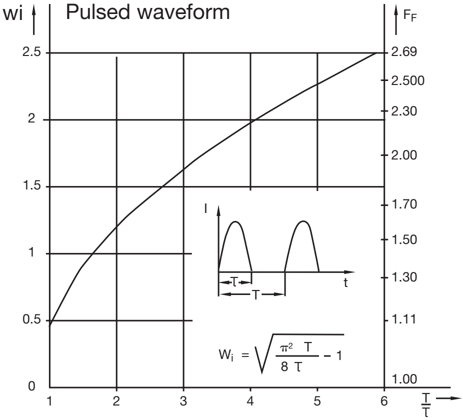
B6C: $C = 0.51 \cdot F_F^{-5.9}$

permissible form-factors

$F_F = 1.2$	1 – 5 kW
$F_F = 1.1$	5 – 15 kW
$F_F = 1.05$	> 15 kW

Experimental determination of the form-factor



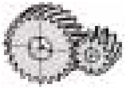
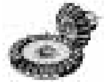
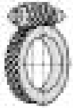


4

Geared motors

5

1 Typical toothed gear designs

	Shaft angle	Standard ratios	Gear efficiency
 Helical gear	0	1 ... 6	Very good
 Bevel gear	90	1 ... 6	Very good
 Worm gear	90	5 ... 60	i = 5: Good i = 60: Poor

Depending on the required shaft angle and ratio range, one or more wheel sets are combined within the gear. The total ratio is calculated by multiplying the individual ratios.

2 Standard materials for geared motors

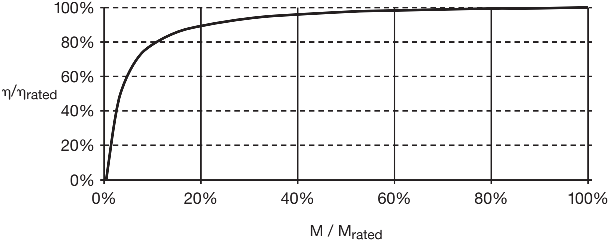
Housing:	Output torque < 100 Nm: Aluminium alloys, cast iron
	Output torque > 100 Nm: Cast iron
Shafts:	Tempering steels C45, C60, 42CrMo 4
Gears:	Case hardening steels 16MnCr5, 20MnCr5, 17CrNiMo6

3 Efficiency

Efficiency = (drive power-power loss)/drive power

In addition to losses in the splines, losses in gaskets and bearings as well as losses in the lubricant must also be taken into account. Due to the relatively high proportion of load-independent losses, gears with low capacity utilisation are less efficient than gears with high capacity utilisation.

Efficiency in relation to capacity utilisation



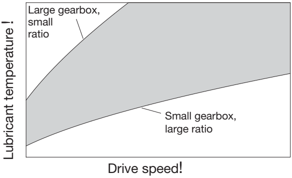
5

4 Lubricants

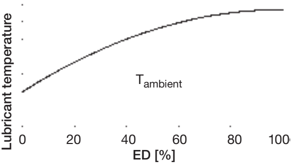
Lubricants reduce friction and transport heat from its place of origin to the housing surfaces. Today, oils are used in geared motors almost without exception.

- CLP mineral oil
  Standard oil for helical and bevel gearboxes
- Synthetic oils, usually polyglycol PGLP
  Standard on worm gearboxes
  In individual cases for helical and bevel gearboxes in extreme temperature ranges
  Cannot be mixed with mineral oils
- Food-compatible oil CLP-H1
  Approved to USDA-H11
- Biologically degradable oil CLP-E
  Synthetic-based diester oil

$T_{lubricant}$(n2)



$T_{lubricant}$(ED)



5 Gearbox temperature

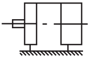
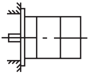
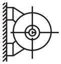
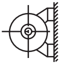
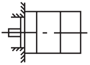
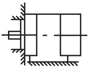
In addition to mechanical components such as gears, bearings and shafts, lubricants and gaskets are important constructional elements in gearboxes.
The service life of lubricants and seals is temperature-dependent. It is therefore vital that permissible temperatures are not exceeded.

The gearbox temperature is the result of the power loss produced and the dissipatable heat.

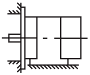
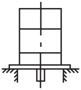
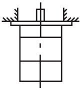
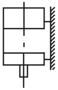
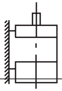
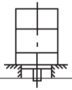
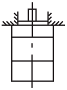
- Power loss ~ $(\text{centre distance})^3$
- Dissipatable heat ~ $(\text{centre distance})^2$

Large gearboxes with small ratios get warmer than small gearboxes with large ratios.

Ideally, oil temperatures should be < 70° (special measures such as fans and oil coolers should be used if necessary). In extreme cases, synthetic lubricants and special sealants (e.g. fluorocaoutchouc) should be used.

Figure	Abb.	Characteristic features
	IM B 3	With 2 bearing covers, housing with feet, free shaft end, mounted on sub-assembly
	IM B 5	With 2 bearing covers, housing without feet, free shaft end Access from side of housing
	IM B 6	With 2 bearing covers pivoted at 90°, free shaft end, housing with feet, wall fastening
	IM B 7	With 2 bearing covers pivoted at 90°, free shaft end, housing with feet, wall fastening
	IM B 8	With 2 bearing covers pivoted at 180°, free shaft end, housing with feet, cover fastening
	IM B 14	With 2 bearing covers, input mounting flange, screws on end face of covers. Only for the smallest machines.
	IM B 34	With 2 bearing covers, input mounting flange, screws on end face of flange, with feet, free shaft end

flange version to DIN EN 60034-7 (VDE 0530, Part 7)

Figure	Abb.	Characteristic features
	IM B 35	With 2 bearing covers, housing with feet, free shaft end, mounting flange in vicinity of bearing
	IM V 1	With 2 locating bearings (may be thrust bearings), flange on lower bearing cover, free shaft end bottom without feet
	IM V 3	Bearing as IM V 1, flange on upper bearing cover, free shaft end top with-out feet
	IM V 5	Bearing as IM V 1, free shaft end bot-tom, housing with feet for wall fastening
	IM V 6	Bearing as IM V 1, free shaft end top, housing with feet, wall fastening
	IM V 18	Design as IM B 14, vertical orientation, input mounting flange, free shaft end bottom. Only for the smallest machi-nes.
	IM V 19	Design as IM B 14, vertical orientation, input mounting flange, free shaft end top. Only for the smallest machines.

Degree of protection via housing (IP code) to DIN EN 60529 (VDE 0470 Part 1)

IP 2 3 C S

Code initial
International Protection

First code number
Protection against contact and simultaneous protection against foreign matter

Second code number
Protection against water

Additional letter
Protection provided by internal cover or clearances

Supplementary letter
Supplementary information

First code number	 0 1 2 3 4 5 6	Against ingression of solid foreign matter (not protected) ≥ 50 mm diameter ≥ 12.5 mm diameter ≥ 2.5 mm diameter ≥ 1.0 mm diameter Dust-protected Dust-tight	Against access to dangerous parts with (not protected) Back of hand Finger Tool Wire Wire Wire
Second code number	 0 1 2 3 4 5 6 7 8	Against ingression of water with consequential damage (not protected) Vertical drip Drip (15° angle) Spray-water Splashing water Hose-water Powerful hose-water Temporary submersion Continuous submersion	
Additional letter	A B C D	–	Against access to dangerous parts with Back of hand Finger Tool Wire
Supplementary letter	 H M S W	Supplementary information specifically for high-voltage equipment Mobile during water test Stationary during water test Weather conditions	–

Missing code numbers replaced with an “x”; additional letter and/or supplementary letter left blank.

Degrees of protection via housing for electrical rotating machines to DIN EN 60034-5 (VDE 0530 Part 5)

IP 2 3 S

Code initial
(International Protection)

First code number
Protection against contact and protection against foreign matter

Second code number
Protection against water

Letter after code number

First code number	0	Machine not protected
	1	Machine protected against foreign matter larger than 50 mm
	2	Machine protected against foreign matter larger than 12 mm
	3	Machine protected against foreign matter larger than 2.5 mm
	4	Machine protected against foreign matter larger than 1 mm
	5	Machine protected against dust
Second code number	0	Machine not protected
	1	Machine protected against dripping water
	2	Machine protected against dripping water when positioned at angles of up to 15°
	3	Machine protected against spray-water
	4	Machine protected against splashing water
	5	Machine protected against hose-water
	6	Machine protected against heavy seas
	7	Machine protected against submersion
	8	Machine protected against continuous submersion
Letter after code numbers	M	Protection against water damage whilst the machine is in operation
	S	Protection against water damage whilst the machine is idle
Letter directly after the IP code letters	W	Machine for use under specific weather conditions

Missing code numbers replaced with an “x”

Labelling of intrinsically safe electrical equipment

Ex II 2G EEx de II C T6

Ex: Labelling for electrical equipment with certificate of conformance or type-examination certificate from an EC testing laboratory or manufacturer certificate for type of protection "n"

2G: Category, can be used in Zone 1 for gases or vapours "G", or Zone 21 for dust "D"

EEx:
E = Built to European standard
Ex = Intrinsically safe equipment

de: Type of protection applied
- o = Oil immersion
- p = Pressurised enclosure
- q = Sand filling
- d = Flameproof enclosure
- e = Increased safety
- i = Intrinsic safety
- n = Zone 2 equipment
- m = Encapsulation

All types of protection used on equipment must be indicated after the type of protection. In the example above:
Main type of protection "d"
Secondary type of protection "e"

II: Area of application explosion group
Group I = Protection against firedamp
II = Explosion protection

C: Explosion group II subdivided for pressurised enclosure "d"

Max. permitted gap	Intrinsically safe circuits "i": Min. ignition current ratio Ratio based on to methane
II A = > 0.9 mm	> 0.8
II B = ≥ 0.5 … 0.9 mm	≥ 0.45 … 0.8
II C = < 0.5 mm	< 0.45

T6:

Temperature class	Surface temperature lower than	Ignition temperature higher than
T1	450°C	450°C
T2	300°C	300°C
T3	200°C	200°C
T4	135°C	135°C
T5	100°C	100°C
T6	85°C	85°C

Important standards, guidelines and ordinances

ExVO, 94/9/EC, ATEX 95, 99/92/EC, ATEX 137, VDE 0165 series, VDE 0170/0171 series

Limit overtemperatures for electronic machines Extract from IEC 60034-1, DIN EN 60034-1 (VDE 0530 Part 1) Overtemperature limit values for machines cooled indirectly with air

Temperature class		A			E			B			F			H		
No.	Method of meas.	Thermometer K	Resistance K	e.t.d. K	Thermometer K	Resistance K	e.t.d. K	Thermometer K	Resistance K	e.t.d. K	Thermometer K	Resistance K	e.t.d. K	Thermometer K	Resistance K	e.t.d. K
1 a)	AC windings on 5000 kW (or kVA) machines or more	–	60	65[1])	–	–	–	–	80	85[1])	–	100	105[1])	–	125	130[1])
1 b)	AC windings on < 5000 kW (or kVA) machines > 200 kW (or kVA)	–	60	65[1])	–	75	–	–	80	90[1])	–	105	110[1])	–	125	130[1])
1 c)	AC windings on 200 kW (or kVA) machines with the exception of windings to No. 1 d) or 1 e)[2])	–	60	–	–	75	–	–	80	–	–	105	–	–	125	–
1 d)	AC windings on < 600 W (or VA) machines[2])	–	65	–	–	75	–	–	85	–	–	110	–	–	130	–
1 e)	AC windings on machines with self-ventilation, without fans (IC 40) and/or with enclosed windings [2])	–	65	–	–	75	–	–	85	–	–	110	–	–	130	–
2	Commutator windings	50	60	–	65	75	–	70	80	–	85	105	–	105	125	–
3	Field windings on AC and DC machines	50	60	–	65	75	–	70	80	–	85	105	–	105	125	–

[1]) These values may have to be adapted for high-voltage AC windings.

[2]) If the superposition method is being used for windings on machines < 200 kW (or kVA), insulated to temperature classes A, E, B and F, the limit values set for overtemperatures may be exceeded by 5 K.

Control modes of electrical machines

IEC 60034-1
DIN EN 60034-1 (VDE 0530 Part 1)

Control mode	Designation/Example
Continuous operation	S1
Short-time operation	S2 60 min
Periodic intermittent operation	S3 35%
Periodic intermittent operation with influence of starting cycle	S4 35% $J_M = 0.25\ \text{kgm}^2$ $J_{ext} = 0.9\ \text{kgm}^2$
Periodic intermittent operation with electrical braking	S5 35% $J_M = 0.25\ \text{kgm}^2$ $J_{ext} = 0.9\ \text{kgm}^2$
Uninterrupted periodic operation	S6 35%
Uninterrupted periodic operation with electrical braking	S7 $J_M = 0.25\ \text{kgm}^2$ $J_{ext} = 3.5\ \text{kgm}^2$
Uninterrupted periodic operation with load/speed variation	S8 $J_M = 0.25\ \text{kgm}^2$ $J_{ext} = 3.5\ \text{kgm}^2$ 10 kW 25% 20 kW 30% 15 kW 45%
Operation with non-periodic load and speed variation	S9 additional entry for reference load
Operation with individual constant loads	S10 $p/\Delta t$ = 1.3/0.5, 1/0.4, 0.8/0.3, r/0.2, TL = 0.7

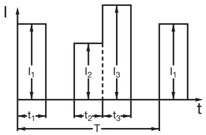
J_M Moment of inertia of motor
J_{ext} Moment of inertia of load
$J_{r.m.s.}$ Motor r.m.s. current

For load cycles the duration of which is relatively short compared with the thermal time constant of the machine, simplified formulas may be entered.

a) r.m.s. motor load

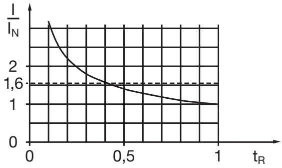
$$I_{r.m.s.} = \sqrt{\frac{I_1^2 t_1 + I_2^2 t_2 + \ldots + I_n^2 t_n}{T}}$$

$$I_{r.m.s.} = I_r \cdot \sqrt{\left(\frac{M}{M_r}\right)^2 \cdot \cos^2\varphi + 1 - \cos^2\varphi)}$$



b) In control mode S3, the motor current which can be supplied I may be higher than the rated current I_r.

$$I = \frac{I_r}{\sqrt{\frac{t}{T}}} = \frac{I_r}{\sqrt{t_R}}$$



At $P/P_r > 1.6$, please consult the manufacturer.

t_R = Relative duty time

How operating frequency affects the ratings of asynchronous motors

f [Hz]	$\frac{P}{P_r}$ [%]	$\frac{n}{n_r}$ [%]	$\frac{M}{M_r}$ [%]
50	100	100	100
60	100	120	83

How the coolant temperature T_c affects rated power

T_c [°C]	40	45	50	55	60
$\frac{P}{P_r}$ [%]	100	95	90	85	80

How the installation height h affects the rated power

h [m above sea level]	1000	2000	3000	4000	5000
$\frac{P}{P_r}$ [%]	100	95	90	85	80

5

Rated currents of motors

Power	DC			Three-phase squirrel-cage motor			Three-phase slipring motor		
	150 V	260 V	440 V	230 V	400 V	500 V	230 V	400 V	500 V
kW	A	A	A	A	A	A	A	A	A
0.75	6.5	3.7	2.3	3.9	2.3	1.7	4.4	2.6	2.0
1.1	9.7	6.0	3.6	5.1	3.0	2.3	6.5	3.8	2.9
1.5	13	8.1	4.8	6.8	3.9	3.0	8.5	5.0	3.7
2.2	20	12	7.1	9.6	5.5	4.2	12	6.6	5.1
3.0	25	15	10	14	7.9	6.0	15	8.2	6.2
3.7	31	19	11	17	9.7	7.4	18	10	7.6
4.0	33	20	12	18	11	7.6	19	11	8.3
5.5	44	27	16	23	14	10	24	14	11
7.5	58	36	21	31	18	14	31	18	14
11	–	52	30	44	25	19	44	25	19
15	–	72	43	56	33	26	56	33	26
18.5	–	89	51	69	41	32	69	41	32
22	–	100	61	83	47	36	82	47	36
30	–	135	80	110	64	48	110	66	47
37	–	170	101	135	79	59	135	80	58
45	–	210	123	160	95	72	160	93	70
55	–	240	143	200	120	87	190	110	84
75	–	330	192	265	155	115	250	150	110
90	–	380	225	305	180	140	305	175	140
110	–	465	275	380	220	165	365	215	150

Standardised rated voltages for DC motors

Power supply via DC speed controller from mains to DIN 40030

Mains conn.	Single-phase		Three-phase					DC speed controller circuit				
Use	Industry		Industry			Ship electrical systems		(B2)A, (B2)C,	B2H	B2C, (B2)A, (B2)C	(B6)A, (B6)C	B6C
Rated frequency of system in Hz	50		50			50	60					
Rated voltage U_n of system in V	230	400	400	500*)	690	400	450**)					
Serial no.	Rated voltage (DC) in V											
1	160							X				
2	180								X			
3		280						X				
4		310							X			
5			420								X	
6			470									X
7				520							X	
8				600								X
9					720						X	
10					810							X
11						350					X	
12							410				X	

*) Not included in DIN IEC 38 “IEC standard voltages, May 1987”.

**) Not included in DIN IEC 38 “IEC standard voltages, May 1987”. Rated voltage acc. to Lloyd’s Shipping Register.

Synchronous speeds on three-phase AC motors

$$n_o = 60 \frac{f}{p} = 120 \frac{f}{2p}$$

$$n = n_o (1 - s) = 60 \frac{f}{p} (1 - s)$$

$$s = \frac{n_o - n}{n_o}$$

$s = 0$ Synchronism

$s = 1$ Rotor speed $n = 0$

n_o = Synchronous speed in rpm

n = Operating speed in rpm

f = Mains frequency in Hz

p = No. of pairs of poles

$2p$ = Number of poles

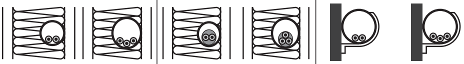
s = Slip

5

2p	f = 50 Hz	f = 60 Hz	f = 100 Hz	f = 200 Hz	f = 400 Hz	p
2	3000	3600	6000	12000	24000	1
4	1500	1800	3000	6000	12000	2
6	1000	1200	2000	4000	8000	3
8	750	900	1500	3000	6000	4
10	600	720	1200	2400	4800	5
12	500	600	1000	2000	4000	6
(14)	428.6	514.3	857.1	1714.3	3428.6	(7)
16	375	450	750	1500	3000	8
(18)	333.3	400	666.7	1333.3	2666.7	(9)
20	300	360	600	1200	2400	10
(22)	272.7	327.3	545.5	1090.9	2181.8	(11)
24	250	300	500	1000	2000	12
(26)	230.8	276.9	461.5	923.1	1846.2	(13)
(28)	214.3	257.1	428.6	857.1	1714.3	(14)
30	200	240	400	800	1600	15

Installation of equipment

Current-carrying capacity of cables or

Type code[2)], (insulating material PVC)	NYM, NYBUY, NHYRUZY, NYIF, H07V-R, H07V-K, NYIFY											
Installation[3)] Ref. inst. type	A1				A2				B1			
	Installation in thermally insulated walls								Installation in cable conduit			
	single cores in conduit in a thermally insulated wall				multi-core cable or multi-core sheathed cable in an electrical conduit in a thermally insulated wall				single cores in conduit on wall			
												
loaded cores	2		3		2		3		2		3	
nom. cross-section copper conductor mm²	capacity in A											
	I_Z	I_n	I_Z	I_n	I_Z	I_n	I_Z	I_n	I_Z	I_n	I_Z	I_n
1.5	16.5	16	14.5	13	18.5	16	14	13	18.5	16	16.5	16
2.5	21	20	19	16	19.5	16	18.5	16	25	25	22	20
4	28	25	25	25	27	25	24	20	34	32[4)]	30	25
4	–	–	–	–	–	–	–	–	–	–	–	–
6	36	35[5)]	33	32[4)]	34	32[4)]	31	25	43	40[6)]	38	35[5)]
10	49	40[6)]	45	40[6)]	46	40[6)]	41	40[6)]	60	50	53	50
10	–	–	–	–	–	–	–	–	–	–	–	–
16	65	63	59	50	60	50	55	50	81	80	72	63
25	85	80	77	63	80	80	72	63	107	100	94	80
35	105	100	94	80	98	80	88	80	133	125[7)]	117	100
50	126	125[7)]	114	100	117	100	105	100	160	160[8)]	142	125[7)]
70	160	160[8)]	144	125[7)]	147	125[7)]	133	125[7)]	204	200[8)]	181	160[8)]
95	193	160[8)]	174	160[8)]	177	160[8)]	159	125[7)]	246	200[8)]	219	200[8)]
120	223	200[8)]	199	160[8)]	204	200[8)]	182	160[8)]	285	250[8)]	253	250[8)]
150	254	250[8)]	229	200[8)]	232	200[8)]	208	200[8)]	–	–	–	–
185	289	250[8)]	260	250[8)]	263	250[8)]	236	200[8)]	–	–	–	–
240	339	315[8)]	303	250[8)]	308	250[8)]	277	250[8)]	–	–	–	–
300	389	315[8)]	348	315[8)]	354	315[8)]	316	315[8)]	–	–	–	–

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 Footnotes on page 88.

conductors to DIN VDE 0298-4

Type code[2], (insulating material PVC)	NYM, NYBUY, NHYRUZY, NYIF, H07V-R, H07V-K, NYIFY								NYY, NYCWY, NYKY, NYM, NYMZ, NYMT, NYBUY, NHYRUZY			
Installation[3] Ref. inst. type	B2				C				E			
	Installation in cable conduit				Installation on a wall				Free in air			
	multi-core cable or multi-core sheathed cable in an electrical conduit on wall				single or multi-core cable or single or multi-core sheathed cable conductor				multi-core cable or multi-core sheathed cable with spacing of at least 0.3 x diameter D from wall			
												
loaded cores	2		3		2		3		2		3	
nom. cross-section copper conductor mm²	capacity in A											
	I_Z	I_n	I_Z	I_n	I_Z	I_n	I_Z	I_n	I_Z	I_n	I_Z	I_n
1.5	17.5	16	16	16	21	20	18.5	16	23	20	19.5	16
2.5	24	20	21	20	29	25	25	25	32	32[4]	27	25
4	32	32[4]	29	25	38	35[5]	34	32[4]	42	40[6]	36	35[5]
4	–	–	–	–	–	–	35[9]	35[5]	–	–	–	–
6	40	35[5]	36	35[5]	49	40[6]	43	40[6]	54	50	46	40[6]
10	55	50	49	40[6]	67	63	60	50	74	63	64	63
10	–	–	50[9]	50	–	–	63[9]	63	–	–	–	–
16	73	63	66	63	90	80	81	80	100	100	85	80
25	95	80	85	80	119	125[7]	102	100	126	125[7]	107	100
35	118	100	105	100	146	125[7]	126	125[7]	157	125[7]	134	125[7]
50	141	125[7]	125	100	178	160[8]	153	125[7]	191	160[8]	162	160[8]
70	178	160[8]	158	125[7]	226	200[8]	195	160[8]	246	200[8]	208	200[8]
95	213	200[8]	190	160[8]	273	250[8]	236	200[8]	299	250[8]	252	250[8]
120	246	200[8]	218	200[8]	317	315[8]	275	250[8]	348	315[8]	293	250[8]
150	–	–	–	–	365	315[8]	317	315[8]	402	400[8]	338	315[8]
185	–	–	–	–	416	400[8]	361	315[8]	460	400[8]	386	315[8]
240	–	–	–	–	489	400[8]	427	400[8]	545	500[8]	456	400[8]
300	–	–	–	–	562	500[8]	492	400[8]	629	500[8]	527	500[8]

Footnotes on page 88.

Footnotes to table: Current-carrying capacity of cables or conductors to DIN VDE 0298-4

Current-carrying capacities I_z[1)] of cables or conductors for fixed installation (installation type A1, A2, B1, B2, C and E) with a permissible conductor temperature of 70 °C and an ambient temperature of 25 °C (Tables A.1 and A.2 from DIN VDE 0298-4 (VDE 0298 Part 4): 1998-11, collated and modified), as well as the selection of overcurrent protection devices for protection against overload.

1) The current-capacity for cables with concentric cores applies only to multi-core versions. Other current-capacity values for cables are to be found in DIN VDE 0276-603 (VDE 0276 Part 603), Section 3G, Table 15

2) A list of type codes and details on the standards met by the cables and conductors is to be found in DIN VDE 0298-1 (VDE 0298 Part 1) and DIN VDE 0298-3 (VDE 0298 Part 3)

3) Further installation types; see tables 2 and 7 of DIN VDE 0298-4 (VDE 0298 Part 4)

4) I_n = 25 A with D- and D0-fuses, which are (at present) not available in Germany for the current rating I_n = 32 A

5) I_n = 32 A with curcuit-breakers, which are (at present) not available in Germany for the current rating I_n = 35 A

6) I_n = 35 A with D- and D0-fuses, which are (at present) not available in Germany for the current rating I_n = 40 A

7) At present, D- and D0-fuses are available up to a maximum rating I_n = 100 A

8) At present, curcuit-breakers are available up to a maximum rating I_n = 125 A, see also footnote 7

9) Not valid for installation on a wooden wall

I_b = operating current of the circuit

I_n = rated or set current of the protective device

I_Z = permissible current loading of the conductor or cable

I_z = tripping current

Conditions:

$I_b \leqq I_n \leqq I_Z$

$I_z \leqq 1{,}45\ I_Z$

External diameters of conductors and cables

The external diameters are average values from different manufacturers

NYM sheathed cable
NYY cable with plastic sheathing
H 05 RR-F light rubber-sheathed cable (NMH + NMH) DIN 57282
H 05 RN-F heavy rubber-sheathed cable (NMH + NSH) DIN 57282
NYCY cable with concentric conductors and plastic sheathing
NYCWY cable with concentric undulating conductors and plastic sheathing

No. of conductors Cross-section mm^2	approx. external diameter NYM mm	NYY mm	H 05 RR-F mm	H 07 RN-F mm	NYCY mm
2 x 1.5	10	11	9	10	12
2 x 2.5	11	13	13	11	14
3 x 1.5	10	12	9	10	13
3 x 2.5	11	13	10	12	14
3 x 4	13	17	–	14	15
3 x 6	15	18	–	16	16
3 x 10	18	20	–	23	18
3 x 16	20	22	–	25	22
4 x 1.5	11	13	9	11	13
4 x 2.5	12	14	11	13	15
4 x 4	14	16	–	15	16
4 x 6	16	19	–	17	18
4 x 10	18	23	–	23	21
4 x 16	22	27	–	27	24
4 x 25	27	28	–	32	30
4 x 35	30	28	–	36	31
4 x 50	–	30	–	42	34
4 x 70	–	34	–	47	38
4 x 95	–	39	–	53	43
4 x 120	–	42	–	–	46
4 x 150	–	47	–	–	52
4 x 185	–	55	–	–	60
4 x 240	–	62	–	–	70
5 x 1.5	11	14	11	14	15
5 x 2.5	13	15	13	17	17
5 x 4	15	17	–	19	18
5 x 6	17	19	–	21	20
5 x 10	20	21	–	26	–
5 x 16	25	23	–	30	–
8 x 1.5	–	15	–	–	–
10 x 1.5	–	18	–	–	–
16 x 1.5	–	20	–	–	–
24 x 1.5	–	25	–	–	–

Conversion table AWG / mm^2

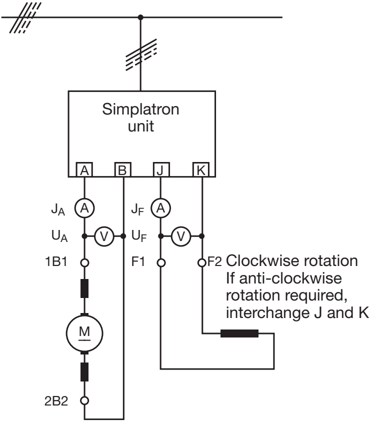
In Europe, the size of a conductor or cable is normally given as a cross-section in mm^2. The designation AWG is sometimes found in catalogs or data sheets. In the USA, the diameter or cross-section of cores is given by a code designation. AWG stands for **A**merican **W**ire **G**auge.

AWG American Wire Gauge	Conductor cross-section in mm^2
30	0.0516
29	0.0646
28	0.080
27	0.102
26	0.105
25	0.162
24	0.205
23	0.255
22	0.32
21	0.407
20	0.51
19	0.65
18	0.79
17	1.01
16	1.305
15	1.65
14	2.08
13	2.63
12	3.3
11	4.15
10	5.27
9	6.6
8	8.34
7	10.25
6	13.25
5	16.9
4	21.0
3	26.6
2	33.7
1	42.2
0	53.4
2/0	67.5
3/0	79.0
4/0	103.8
5/0	135.0
6/0	170.0

Connection of electric motors

According to EN 60034-5, the power that is stated on the nameplate is always the shaft power P_2 of the motor. The input powerP_1 and the efficiency η can be calculated from the nameplate data and from measurements.

1. DC shunt-wound motor

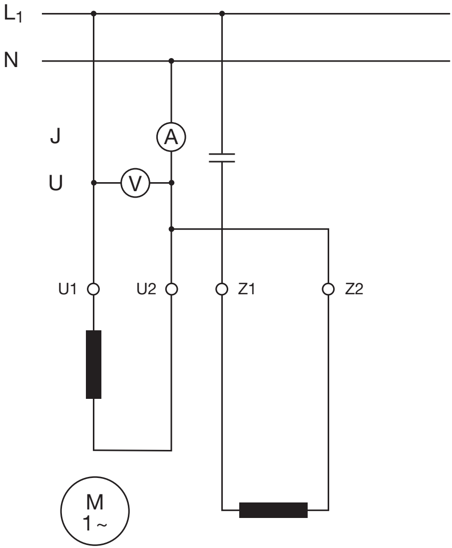


If the armature (rotor) and field (stator) voltages are the same, then the motor terminals J, K are labelled as C, D

$$P_1 = U_A I_A + U_F I_F \qquad \eta = \frac{P_2}{U_A I_A + U_F I_F}$$

armature efficiency $\eta_A = \frac{P_2}{U_A I_A}$

2. Single-phase AC motor

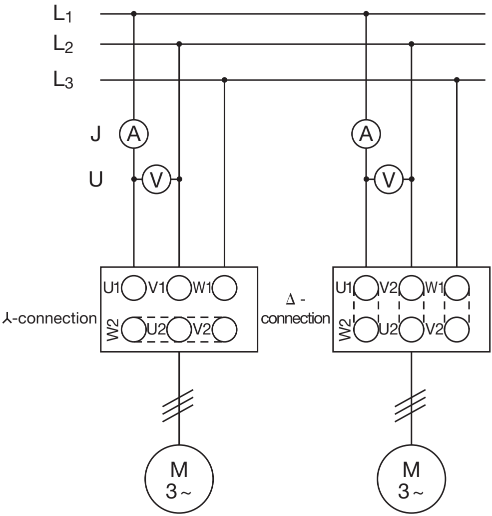


Clockwise rotation: if anti-clockwise rotation is required, interchange Z1 and Z2

$$P_1 = U\,I\cos\varphi \qquad\qquad \eta = \frac{P_2}{U\,I\cos\varphi}$$

6

3. 3-phase motor

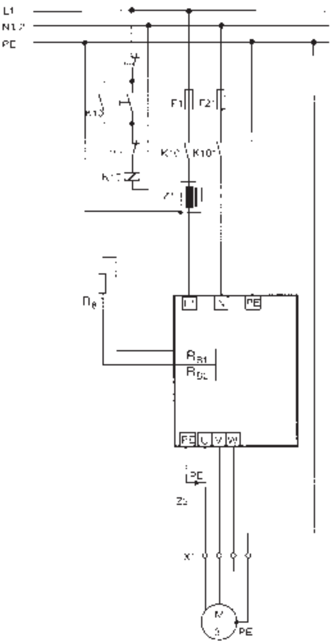


Clockwise rotation: if anti-clockwise rotation is required, interchange any two phases

generalized:

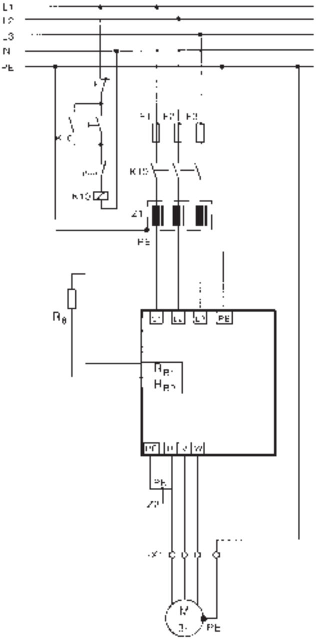
$$P_1 = \sqrt{3}\, U\, I \cos \varphi \qquad \eta = \frac{P_2}{\sqrt{3}\, U\, I \cos \varphi}$$

4. Frequency inverter and 3-phase motor
connected to single-phase supply 1 x 220 ... 230 V



6

5. Frequency inverter and 3-phase motor
connected to 3-phase supply 3 x 400 ... 460 V / 480 V



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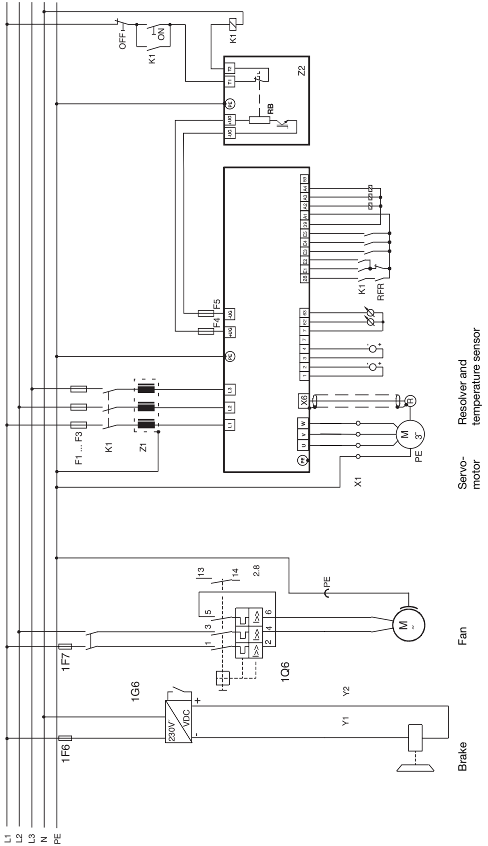
6. Servo-inverter and servomotor



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Approvals and standards

7

Approvals
Examples

Belgium
Comité Electrotechnique Belge
Belgisch Elektrotechnisch Comité
(CEBEC)

b

Denmark
Danmarks Elektriske Materielkontrol
(DEMKO)

d

Finland
(FIMKO)

f

France
Union Technique de l'Electricité
(UTE)

x

Netherlands
Naamloze Vennootschap tot Keuring
van Electrotechnische Materialien
(KEMA)

kl

Norway
Norges Elektriske Materiellkontrol
(NEMKO)

n

Sweden
Svenska
Elektriska Materielkontrollanstalten
(SEMKO)

s

Switzerland Schweizerischer Elektrotechnischer Verein (SEV)		t
Germany Verband Deutscher Elektrotechniker (VDE)		v
Austria Österreichischer Verband für Elektrotechnik (ÖVE)		j
USA Underwriters Laboratories (UL)	Listing	u
	Recognition	r
Canada Canadian Standards Association (CSA)		a
Russia Gosstandart (GOST Re)		

There are new approval requirements in the following countries: Slovakia, Poland, South Africa, China and Russia

Approval establishments

USA
USA
UL

Canada
CDN
CSA

Croatia
CRO
ZIK

Romania
RO
ICECON

Russia
RUS
GOST-R

Czech Republic
CR
EZU

Hungary
H
MEEI

South Africa
SA
SABS

Slovakia
SK
SKTC

Shipping registration

Germany
Germanischer
Lloyd
GL

Great Britain
Lloyd's Register of
Shipping
LR

France
Bureau
Veritas
BV

Russia
Russian Maritime
Register of Shipping
RS

Italy
Registro Italiano
Navale
RINA

Norway
Det Norske Veritas
DNV

Poland
Polski Rejestr
Statkow
PRS

Important standards and regulations for inverter-fed drives

73/23/EEC	Low voltage Directive
89/336/EEC	Directive on Electromagnetic Compatibility (EMC Directive)
98/37/EC	Machinery directive
CISPR 22 EN 55022 DIN EN 55022 (VDE 0878 Part 22)	Information technology equipment: RFI-characteristics limits and measurement methods
DIN 19226	Control technology
DIN 40110	AC-variables
DIN 41751	Cooling of semiconductor inverter equipment
DIN 41752	Power designations of semiconductor inverter equipment
DIN 41756	Loading of inverters, operating modes, loading classes and load types
DIN VDE 0298-4	Use of cables and isolated conductors for power plants; recommended value for maximum current capacity of cables and conductors for laying in buildings and of flexible conductors
EMVG	Law on the electromagnetic compatibility of equipment
EN 50102 DIN EN 50102 (VDE 0470 Part 100)	Enclosure protection for electrical apparatus (equipment) against exterior mechanical effects (IK-Code)
EN 50178 DIN EN 50178 (VDE 0160)	Equipment for high-current installations with electronic apparatus
EN 50216 DIN EN 50216 (VDE 0532)	Transformers and inductors

IEC 60034 EN 60034 DIN EN 60034 (VDE 0530)	Rotating electrical machines
IEC 60034-5 EN 60034-5 DIN VDE 60034-5 (VDE 0530 Part 5)	Calibration of the enclosure protection for running machines (IP-Code)
IEC 60050 DIN IEC 60050	Conceptions for current inverters; building and type of function, disqualification, electrical variables, calculations
IEC 60146 EN 60146 DIN EN 60146 (VDE 0558)	Inverters; basic requirements
IEC 60204 EN 60204 DIN EN 60204 (VDE 0113)	Machine safety; electrical equipment Machines

IEC 60349-2 ENV 60349-2 DIN EN 60349-2 (VDE 0115 Part 400-2)	Rotating electrical machines in rail and road vehicles; inverter-fed AC motors
IEC 60364-4-43 IEC 60364-4-473 DIN VDE 0100-430	Overcurrent protection of cables and conductors
IEC 60411-2	Conductor inverters for rail; complementary technical information
IEC 60439-1 EN 60439-1 DIN EN 60439-1 (VDE 0660 Part 500)	Requirement and testing of low-voltage switchgear
IEC 60529 EN 60529 DIN EN 60529 (VDE 0470 Part 1)	Enclosure protection (IP Code)
IEC 60664 DIN VDE 0110	Isolation coordination for apparatus in low voltage installations
IEC 60755	General requirements for difference-current activated protective devices
IEC 60971 DIN IEC 60971	Designation system for inverter circuits
IEC 61000-4-2 EN 61000-4-2 DIN EN 61000-4-2 (VDE 0847 Part 4-2)	Electromagnetic Compatibility (EMC); test and measurement methods; testing for interference immunity to electrostatic discharge; EMC basic standard
IEC 61000-4-3 EN 61000-4-3 DIN EN 61000-4-3 (VDE 0847 Part 4-3)	Electromagnetic Compatibility (EMC); test and measurement methods; testing for interference immunity to high HF electromagnetic fields
IEC 61000-4-4 EN 61000-4-4 DIN EN 61000-4-4 (VDE 0847 Part 4-4)	Electromagnetic Compatibility (EMC); test and measurement methods; testing for interference immunity to fast electrostatic transients/bursts; EMC basic standard
IEC 61000-4-5 EN 61000-4-5 DIN EN 61000-4-5 (VDE 0847 Part 4-5)	Electromagnetic Compatibility (EMC); test and measurement methods; testing for interference immunity to pulse voltages

IEC 61000-6-1 EN 61000-6-1 DIN EN 61000-6-1 (VDE 0839 Part 6-1)	Electromagnetic compatibility – basic standard interference immunity for residential buildings, shops and small businesses in the textile industry
IEC 61000-6-2 EN 61000-6-2 DIN EN 61000-6-2 (VDE 0839 Part 6-2)	Electromagnetic compatibility – basic standard interference immunity in industrial areas
IEC 61000-6-4 EN 61000-6-4 DIN EN 61000-6-4 (VDE 0839 Part 6-4)	Electromagnetic compatibility – basic standard interference immunity for industrial areas
IEC 61131-3 EN 61131-3 DIN EN 61131-3	Programming languages for programmable logic controllers
IEC 61136-1 EN 61136-1 DIN EN 61136-1	Controllable electrical drive systems; general requirements, especially for DC-drives
IEC 61287-1	Inverters from locomotive; Quality and test procedure
IEC 61800-3 EN 61800-3 DIN EN 61800-3 (VDE 0160 Part 100)	EMC product standards for variable-speed electrical drives
ISO 9000 EN ISO 9000 DIN EN ISO 9000	standards for quality management systems and quality assurance / QM presentation
ISO 14001 EN ISO 14001 DIN EN ISO 14001	Environmental management systems: specification and instructions for use
VBG 4	Accident prevention regulations for electrical plant and equipment
VDE 0100	Regulations for the installation of high-current equipment with voltage ratings up to 1000 V

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