28/30

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PROBLEM 1: A wound-field dc motor is driving a load whose torque requirement increases linearly with speed (squared-power load) and reaches 5 Nm at a speed of 1400 rpm. The armature terminal voltage is held to its rated value. At the rated flux the no-load speed is 1500 rpm and the full-load speed is 1400 rpm. If the flux is reduced to 80 % of the rated value, calculate the new steady-state speed.

$$T_L = \left(\frac{T_{FL}}{\omega_{FL}}\right)\omega. \qquad \frac{T_{FL}}{\omega_{FL}} = \frac{5}{1400}$$

$$\omega_{NL} = \frac{V}{k\Phi} - \frac{R_a \cancel{T}^{0}}{(k\Phi)^2} = 1500\text{rpm}$$

$$\therefore \quad \frac{R_a T_{FL}}{(k\Phi)^2} = 100\text{rpm} \Rightarrow \frac{R_a}{(k\Phi)^2} = 20$$

$$\omega_{WK} = \frac{V}{0.8\,k\Phi} - \frac{R_a}{0.64\,(k\Phi)^2}\left(\frac{T_{FL}}{\omega_{FL}}\right)\omega_{WK}$$

$$\omega_{WK} = 1875 - 0.1116\,\omega_{WK}$$

$$\omega_{WK} = \frac{1875}{1.1116} = 1{,}686.76\text{rpm}$$

PROBLEM 2: The specification sheet for the Maxon 250 W, 48 V, 6500 rpm, EC dc motor is shown on page 161. Compute the armature current, applied voltage, and machine efficiency for the condition shown in line 10 of motor data. What are the amplitude of per-phase back emf and the rms per-phase current?

$\omega_{NL} = 6500\text{rpm} = 680.68 \text{ rad s}^{-1}$

$I_{NL} = 290 \text{mA}$

$R_{ph-ph} = 1.04\Omega$

$T_L = 0.306 \text{ Nm} \ @ \ 523.6 \text{ rad s}^{-1}$

$K = 0.071$

$T_{EM} = T_0 + T_{NL}$

$= 0.306 + k I_{NL}$

$= 0.32659 \text{ Nm}$

$I_a = 4.6\text{A}$

$E = k\omega = 37.1756 \text{ V}$

$V = E + I_a R = 41.96 \text{ V}$

$P_o = T_o \omega = 160.22 \text{W}$

$P_i = V I_a = 193.02 \text{ W}$

$\eta = 83\%$

$E_{ph} = \frac{E_{ph-ph}}{2} = \frac{37.1756}{2} = 18.59 \text{ V}$

$I_{ph\,rms} = \sqrt{\frac{2}{3}}\, I_a = 3.76 \text{ A}$

PROBLEM 3: The specification sheet for the TK 164-110-03 permanent magnet motor is attached. Estimate the no-load core, friction and windage losses and determine the per-phase no-load current. Under full-load determine the applied per-phase current and voltage, power factor for the full power condition under water cooling: 13.92 kW output power at 173.99 rad/s. Note that the specified winding parameters are twice the per-phase parameters.

$P_o = 13.92\,kW$ $\quad k = \frac{3.05}{3} = 1.016\ Nm/A$

$\omega = 173.99\ rad/s$ $\quad R_{ph} = 0.53\Omega$ $\quad L_s = 3.29\,mH$

$P_o = T\omega \Rightarrow T = \frac{13920}{173.99} = 80\,Nm$

$\frac{T}{3k} = I_{ph} = 26.23\ A$

$E = k\omega = 176.89\ V$

$V_{ph} = E + I_{ph} R_s + j X_{Ls} I_{ph}$

$X_{Ls} = 2\pi f_e L$ $\quad f_e = 173.99 \times \frac{\overset{P.P.}{6}}{2\pi} = 166\,Hz$

$V_{ph} = [176.89 + (26.23 \times 0.53)] + j[2\pi 166 \times 3.29 \times 10^{-3} \times 26.23]$

$= 190.792 + j\,90.01$

$= 210.96 \angle 25.26^\circ$

$\cos\phi = \cos(25.26) = 0.904$

$\cancel{P_i = 3 V_{ph} I_{ph} \cos\phi = 15.013\,kW}$

$\cancel{P_{LOSS} = 1.093\,kW}$

$P_{cu} = 3 I_{ph}^2 R_s = 1.093\,kW$

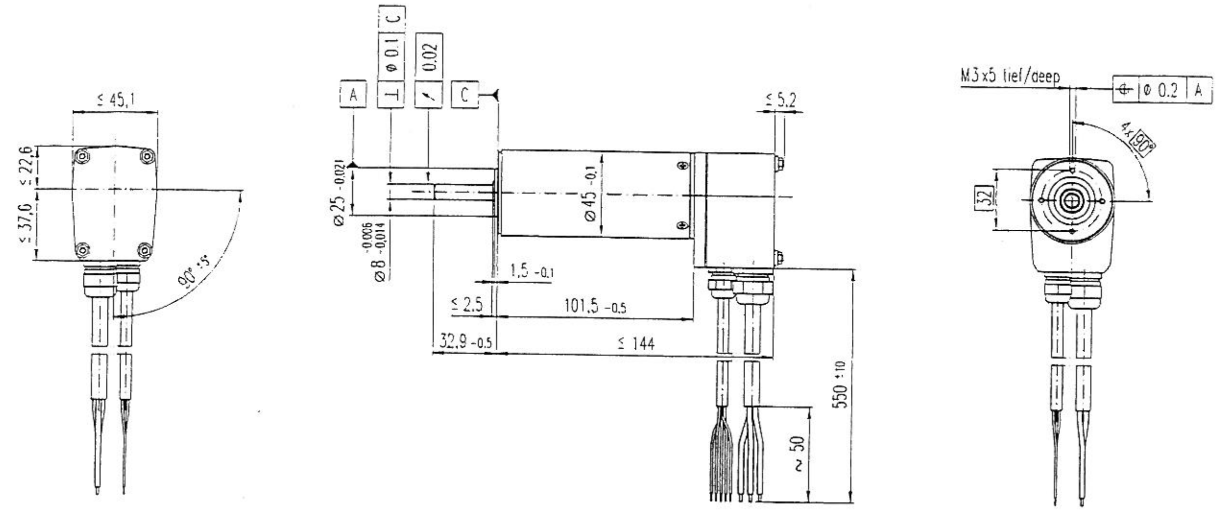
$P_i = 16.68\,kW$

$P_{LOSS} = 2.76\,kW$

$P_{CFW} = P_{LOSS} - P_{cu} = 1.668\,kW$

8

45 Ø45 mm, brushless, 250 Watt, CE approved



M 1:4

- Stock program
- Standard program
- Special program (on request!)

Order Number

Motor Data

			Y-circuit 136207	Y-circuit 136208	Y-circuit 136209	Δ-circuit 136210	Δ-circuit 136211	Δ-circuit 136212
1	Assigned power rating	W	250	250	250	250	250	250
2	Nominal voltage	Volt	24.0	36.0	48.0	24.0	36.0	48.0
3	No load speed	rpm	5300	6300	6500	9100	11000	11100
4	Stall torque	mNm	2250	3000	3250	3910	5260	5670
5	Speed / torque gradient	rpm / mNm	2.40	2.10	2.00	2.34	2.10	1.97
6	No load current	mA	435	370	290	1139	1062	818
7	Terminal resistance phase to phase	Ohm	0.46	0.64	1.04	0.15	0.21	0.35
8	Max. permissible speed	rpm	12000	12000	12000	12000	12000	12000
9	Max. continuous current at 5000 rpm	A	7.10	6.00	4.70	12.50	10.60	8.20
10	Max. continuous torque at 5000 rpm	mNm	283	300	306	286	303	304
11	Max. efficiency	%	83	85	85	84	85	86
12	Torque constant	mNm / A	43.3	54.0	71.0	25.0	31.2	41.0
13	Speed constant	rpm / V	220	175	135	382	306	233
14	Mechanical time constant	ms	5	5	5	5	5	5
15	Rotor inertia	gcm^2	209	209	209	209	209	209
16	Terminal inductance phase to phase	mH	0.170	0.260	0.440	0.060	0.090	0.150
17	Thermal resistance housing-ambient	K / W	1.7	1.7	1.7	1.7	1.7	1.7
18	Thermal resistance winding-housing	K / W	1.1	1.1	1.1	1.1	1.1	1.1
19	Thermal time constant winding	s	16	16	16	16	16	16
20	Thermal time constant stator	s	850	850	850	850	850	850

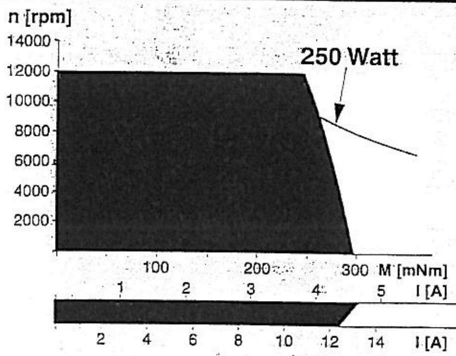
Specifications

- Motor connections — Screw fitting for cable PG7
- Axial play at axial load < 20 N — 0 mm
  - > 20 N — max. 0.14 mm
- Preloaded ball bearing
- Max. ball bearing loads
  - axial (dynamic) — 20 N
  - radial (5 mm from flange) — 180 N
  - Force for press fits (static) — 170 N
  - (static, shaft supported) — 5000 N
- Radial play ball bearing — 0.02 mm
- Ambient temperature range — -20 ... +125°C
- Max. permissible winding temperature — +125°C
- Weight of motor — 1150 g
- Protection — IP54
- 2 pole permanent magnet
- Values listed in the table are nominal.
- Connection (Cable AWG 16)
  - Cable 1 — Motor winding 1
  - Cable 2 — Motor winding 2
  - Cable 3 — Motor winding 3

  Connection (Cable AWG 24)
  - Cable white — Hall sensor 3
  - Cable brown — Hall sensor 2
  - Cable green — Hall sensor 1
  - Cable yellow — GND
  - Cable grey — V_{Hall} 4.5 ... 24 VDC
- Options: Temperature monitoring

  PTC resistance micropille 110°C
  - R 25°C — < 0.5 kΩ
  - R 105°C — = 1.2 ... 1.5 kΩ
  - R 115°C — = 7 ... 13 kΩ
  - R 120°C — = 18 ... 35 kΩ
- For wiring diagram for Hall sensors, see p. 26
- Options: motor connection with plug

Operating Range



136209 Motor with high resistance winding

136210 Motor with low resistance winding

Comments

Details on page 149

Curve of constant assigned power rating

Continuous operation
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit

Short term operation
The motor may be briefly overloaded (recurring).

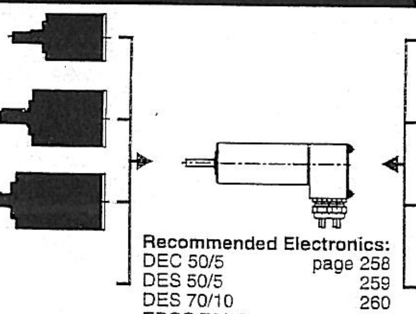
maxon Modular System

Overview on page 17 - 21

Planetary Gearhead
Ø42 mm
3 - 15 Nm
Details page 219

Planetary Gearhead
Ø52 mm
4 - 30 Nm
Details page 221

Planetary Gearhead
Ø62 mm
8 - 50 Nm
Details page 223



Recommended Electronics:

DEC 50/5	page 258
DES 50/5	259
DES 70/10	260
EPOS 70/10	263
MIP 50, MIP 100	265
Notes	17

Digital Encoder HP HEDL 9140
500 CPT, 3 channels
Details page 241

Resolver
Ø26 mm
10 V
Details page 247

Brake
Ø28 mm, 24 VDC
0.4 Nm
Details page 270

April 2004 edition / subject to change

Technical Data Summary TK 164

High power medium speed spindle motors
Applications:
Direct drive lathes
Swiss type lathes
Speed up to 5000 rpm, 40-200 Nm
Short duty constant power

	Symbol	TK 164-60-04	TK 164-110-03	TK 164-250-09	Units
Reference data (winding independent)					
Nominal torque, S1,0 speed, conduction+convection cooled IC 418 1)	Tnc	19	40	106	*Nmrms*
Nominal torque, S1, 0 speed, water cooled 2)	Tnw	37	80	209	*Nmrms*
Peak torque, S6 10% 1)	Tpk	54	114	302	*Nmrms*
Maximum torque 3)	Tul	93	171	389	*Nm*
Maximum structural speed	Pn	500	500	500	*rad/sec*
Critical flux control torque 4)	Pf	86	157	366	*Nm*
Motor constant	Tw	2,33	3,63	6,31	*Nm/sqrt(W)*
Pole number	PN	12	12	12	
Connection		Y	Y	Y	
Physical data (winding independent)					
Rotor inertia	Jm	4,30	7,30	16	*mkgm2*
Acceleration at maximum torque	apk	12576	15595	18855	*rad/s2*
Outer diameter	Dout	164	164	164	*mm*
Rotor hole diameter	Din	96	96	96	*mm*
Overall stator length	Stkout	102	152	292	*mm*
Stack length	Stk	60	110	250	*mm*
Stator mass	Msta	4,8	8	17	*kg*
Rotor mass	Mrot	1,3	2,4	5,5	*kg*
Insulation		Class H - F	Class H - F	Class H - F	
Protection		IP 00	IP 00	IP 00	
Thermal data (winding independent)					
Thermal imp. assumed for cond. Cooling 1)	Rthc	0,390	0,214	0,093	*K/W*
Thermal impedance, motor to cooling frame 2)	Rthw	0,092	0,050	0,021	*K/W*
Thermal capacity	Cth	2.016	3.360	7.140	*J/K*
Thermal time constant cond cooling 1)	Tc	786	719	664	*sec*
Thermal time constant, water cooled 2)	Tw	185	168	150	*sec*
Loss at Tnc	LOc	267	491	1.120	*W*
Loss at Tnw	LOw	1.030	1.880	4.380	*W*
Coolant flow, 5 C temp rise, 35 C inlet	Cfl	3,0	5,4	12,6	*lit/min*
Treshold of built-in PTC	PTCt	130	130	130	*oC*
Electrical data (winding dependent)					
Nominal speed (knee speed) 5)	wn	173,29	173,99	52,40	*rad/sec*
Nominal power, water cooling, knee speed 6)	Pnw	6,41	13,92	10,95	*kW*
Back E.M.F. between phases	Ke	1,80	1,76	5,13	*Vs*
Torque constant	Kt	3,13	3,05	8,89	*Nm/Arms*
Temp.coeff. of E.M.F. and Kt	dKe/dT	-0,09	-0,09	-0,09	*%/oC*
Winding resistance, 20oC	Rw	2,69	1,06	2,98	*Ohm*
Winding inductance	Lw	12,63	6,58	24,00	*mH*
Nominal current, zero speed 1)	In0	6,08	13,12	11,92	*Arms*
Nominal current, zero speed, 2)	In	12,46	27,62	24,74	*Arms*
Maximum current 3)	Ipk	37,19	70,12	54,69	*Arms*
Frequency	fn	166	166	50	*Hz*
Efficiency at rated power 6)	n	0,86	0,88	0,71	

Definitions:
1) Motor assembled in light alloy case with outer surface = 500% of
2) Water cooled motor, water inlet temperature = 35 C, copper temp. 120
3) Torque at which magnetic saturation prevents further overloading
4) Knee torque corresponding to unlimited constant power operation
5) Limit of constant torque operation with 400 Vac supply

P19, Q6(b) Summer 2006

250 W, 24 V, 5300 rpm

$k = 0.0433 \text{ Nm/A}$

$R_{ph\text{-}ph} = 0.46\,\Omega$

$L_{ph\text{-}ph} = 0.17 \text{ mH}$

$$\left.\begin{array}{l} I_{NL} = 0.435 \text{ A} \\ @\ 24 \text{ V} \end{array}\right\} \text{N.L.}$$

R_{ph} L_{ph} L_{ph} R_{ph} R_{ph} L_{ph}

Line 10:

$$\left.\begin{array}{l} T_o = 0.283 \text{ Nm} \\ N = 5000 \text{ rpm} \\ \Rightarrow \omega = \frac{N}{60} \times 2\pi = 523.6 \text{ rad s}^{-1} \\ \Rightarrow P_o = T_o \cdot \omega = 148.2 \text{ W} \end{array}\right\} \text{F.L.}$$

Total EM torque

$$\underset{\text{wlindage/friction}}{T_{EM} = \underbrace{T_o}_{\text{o/p mech.}} + \underbrace{T_{NL}}_{\text{windage/friction}}}$$

$\Rightarrow T_{EM} = T_o + k I_{NL}$

$= 0.283 + 0.0433 \times 0.435$

$= 0.302 \text{ Nm}$

$\Rightarrow I_{\cancel{ph}\,a} = \frac{T_{EM}}{k}$

$= 6.97 \text{ A}$

$\Rightarrow V_{ph\text{-}ph} = E_{ph\text{-}ph} + R_{ph\text{-}ph} \cdot I_{\cancel{ph}\,a}$

But $E_{ph\text{-}ph} = k\,\omega$

$= 0.0433 \times 523.6 \text{ V}$

$= 22.7 \text{ V}$

$\Rightarrow V_{ph\text{-}ph} = 22.7 + 0.46 \times 6.97 \text{ V}$

$= 25.9 \text{ V}$

$\Rightarrow$ Input Elec. Power

$P = V_{ph\text{-}ph} \cdot I_{\cancel{ph}\,a}$

$= 180 \text{ W}$

$\Rightarrow$ Efficiency $= \eta = \frac{P_o}{P}$

$= 82.3\%$