Quick Startup Guide

TPM(A)

004 – 110

BOSCH REXROTH

IndraDrive

Technical changes reserved!

Table of Contents

Modification History

1 General Information and Safety Instructions

This guide serves as an aid during start-up and inspection of TPM motor gear units with servo amplifiers. It contains the following points:

- Start-Up information
- Parameter lists for the TPM series
- Connection schematic for TPM
- Assignment table TPM – Servo amplifier - cable set

Please be sure to carefully read through this document before starting up the TPM and also be sure to read the documentation provided by the manufacturer of the servo amplifier.

WITTENSTEIN motion control will not be held liable for the consequences of the improper, negligent, or incorrect installation or setting of the servo amplifier's operating parameters.

All of the installation, operation, and safety information provided in the servo amplifier documentation is to be observed.

Observe all of the national safety regulations and guidelines of the country where the device is being used. All transportation, installation, start-up, and service work is to be performed by qualified technicians. Qualified technicians are those who are completely familiar with the assembly, installation, and operating procedures, as well as all warnings and safety measures in accordance with the country-specific regulations. Furthermore, they are trained, instructed, and authorised to set the electrical circuits and other devices into operation in accordance with safety regulations.

The drives are intended to be installed in machines being used in commercial applications. You may only operate the equipment if you comply to the national EMC regulations (refer to the servo amplifier documentation for installation information pertaining to EMC) as they are defined for the given application.

Note: All of the product brand names which appear in this Quick Start Guide are trademarks of the relevant companies. If the ® and/or ™ symbols are omitted, this does not imply that the name is a free brand name.

2 Name plate data details

The following specifications can be found on the identification plate. Please select the input parameters corresponding to the nameplate values of your drive.

TPM 010–091 M–600 K–BP 1–015 IF STD

Size
TPM 004 / 010 / 025 / 050 / 110
TPMA 025 / 050 / 110

Ratio
21 / 31 / 61 / 91 (TPM)
110 / 154 / 220 (TPMA)

Motor encoder
R = Resolver
S = Singleturn Heidenhain EnDat®
M = Multiturn Heidenhain EnDat®
N = Singleturn Stegmann Hiperface®
K = Multiturn Stegmann Hiperface®
I = Heidenhain incremental encoder

Intermediate voltage
320
600

Temperature sensor
P = PTC STM 160 in accordance with
    DIN 44081 / 44082
N = NTC
K = KTY 84-130

Plug form
STD = angle
SEG = straight
XXX = custom

Standard
IF = industry standard
UL = UL recognised
file   E220160

Stator length

Clearance specification
1 = Standard < 3 arcmin
        (TPM 004: < 5 arcmin)
0 = Reduced < 1 arcmin
        (TPM 004: < 3 arcmin)

Brake
BP = Permanent magnetic
brake
OH = Without brake

3   Parameterization

To operate the TPM together with a drive of the IndraDrive-family the motor parameters need to be put in.

The tables in section 4, 5 and 6 contain all of the parameters that are required for the initial start-up of a TPM motor-gear unit from WITTENSTEIN motion control together with a Bosch Rexroth IndraDrive. When the TPM and the servo amplifier are properly connected, these parameters guarantee that the TPM can be operated without load in speed control. Based on these default settings, the dynamics of the speed loop can be optimized depending on the application.

Together with the DriveTop-Software the data can be loaded via the single parameter dialog.

3.1   Parameter input via single parameter

With this option each parameter number and each parameter value needs to be put in. In this case it is necessary to use the parameters from table in section 4, 5 or 6 depending on the TPM you use.

3.1.1   Starting the dialog single parameter input
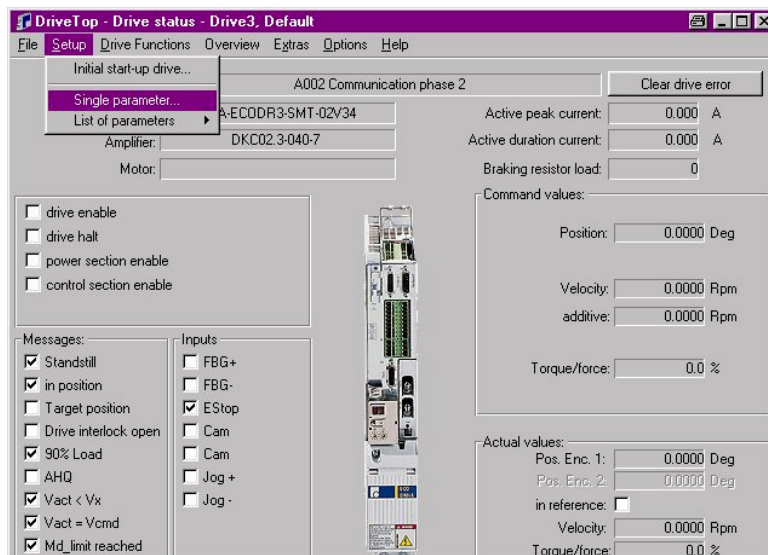
3.1.2   Parameter input

Input of p4014 is sufficient for selecting Parameter P-0-4014, s109 for S-0-0109.

4 Parameters TPM 600V ratio 21/31

Data for combinations not shown here are available on demand.

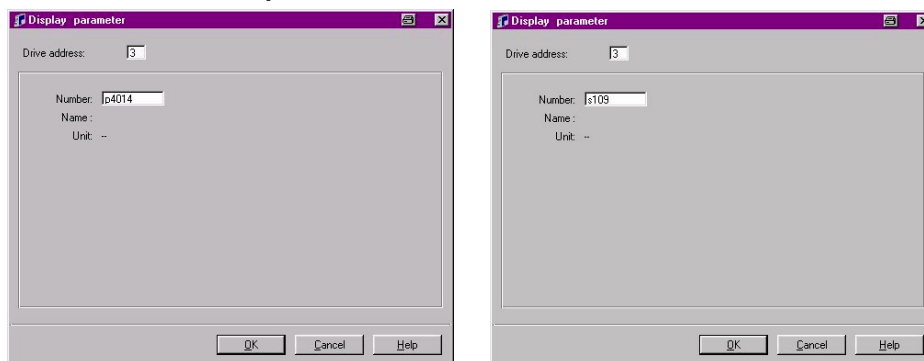| Code	Description	TPM 004	TPM 010	TPM 025	TPM 050	TPM 110
	Statorlength	30	30	45	60	75
S-0-0141	Motor type	TPM004	TPM010	TPM025	TPM050	TPM110
P-0-4014	Type of motor	0	0	0	0	0
P-0-0001	Switching frequency [kHz]	8	8	8	8	8
P-0-0018	Number of pole pairs	4	4	6	6	6
P-0-0051	Torque constant [Nm/Aeff]	0,67	0,83	1,16	0,91	1,51
P-0-0074	Encoder type 1 (motor encoder) Resolver / EnDat / Hiperface			10 / 8 / 4		
P-0-0109	Torque peak limit i = 21 [%]	302	385	241	273	217
	Torque peak limit i = 31[%]	258	385	203	238	217
P-0-0508	Commutation offset Resolver / EnDat			512		
	Commutation offset Hiperface			341		
P-0-0510	Rotor inertia					
	i = 21 without brake [kgm²]	0,000017	0,000041	0,000248	0,000946	0,001367
	i = 21 with brake [kgm²]	0,000023	0,000049	0,000257	0,000969	0,001542
	i = 31 without brake [kgm²]	0,000017	0,000040	0,000244	0,000935	0,001311
	i = 31 with brake [kgm²]	0,000023	0,000048	0,000253	0,000958	0,001486
P-0-4016	Direct-axis inductance of motor [mH]	15,3	10,2	5	1,2	2,7
P-0-4017	Quadrature-axis inductance of motor [mH]	15,3	10,2	5	1,2	2,7
P-0-4048	Stator resistance [Ohm]	47,40	19,30	3,80	0,36	0,72
S-0-0043	Velocity polarity parameter Resolver / EnDat / Hiperface			0111 / 0000 / 0000		
S-0-0055	Position polarities Resolver / EnDat / Hiperface			1111 / 0000 / 0000		
S-0-0085	Torque polarity parameter Resolver / EnDat / Hiperface			0111 / 0000 / 0000		
S-0-0092	Bipolar torque / force limit value i = 21 [%]	302	385	241	273	217
	Bipolar torque / force limit value i = 31 [%]	258	385	203	238	217
S-0-0106	Current loop proportional gain 1 [V/A]	60	32	13,5	5,3	11,9
S-0-0107	Current loop integral action time 1 [ms]	0,3	0,7	1,1	6,67	7,5
S-0-0109	Motor peak current i = 21 [Aeff]	2,4	5	10,6	41,8	26,2
	Motor peak current i = 31 [Aeff]	2,1	5	8,9	36,4	26,2
S-0-0111	Motor current at standstill [Aeff]	0,80	1,30	4,40	15,30	12,10
S-0-0113	Maximum motor speed [1/min]	7000	7000	6000	5000	4300
S-0-0116	Feedback 1 resolution Resolver / EnDat / Hiperface	1 / 512 1024		1 / 2048 / 1024		
S-0-0201	Motor warning temperature [℃]	130	130	130	130	130
S-0-0204	Motor shutdown temperature [℃]	145	145	145	145	145
S-0-0100	Velocity loop proportional gain [As/rad]	0.05	0.05	0.2	0.2	0.2
S-0-0101	Velocity loop integral action time [ms]	10	10	10	10	10
P-0-0004	Velocity loop smoothing time constant [µs]	250	250	250	250	250
P-0-0525 [1]	Holding brake control word	100[1]	100[1]	100[1]	100[1]	100[1]
S-0-0206	Drive on delay time [ms]	12	25	25	50	50
S-0-0207	Drive off delay time [ms]	6	6	6	10	10
P-0-0540	Torque of holding brake [Nm]	0,8 0,4(Resolver)	1,8	1,8	15	15

[1] In case of TPM without brake, the parameter P-0-0525 has to be set to 0.

5 Parameters TPM 600V ratio 61/91

Data for combinations not shown here are available on demand.

Code	Description	TPM 004	TPM 010	TPM 025	TPM 050	TPM 110
	Statorlength	15	15	15	15	60
S-0-0141	Motor type	TPM004	TPM010	TPM025	TPM050	TPM110
P-0-4014	Type of motor	0	0	0	0	0
P-0-0001	Switching frequency [kHz]	8	8	8	8	8
P-0-0018	Number of pole pairs	4	4	6	6	6
P-0-0051	Torque constant [Nm/Aeff]	0,45	0,77	0,76	1,02	0,91
P-0-0074	Encoder type 1 (motor encoder) Resolver / EnDat / Hiperface	10 / 8 / 4				
P-0-0109	Torque peak limit i = 21 [%]	205	305	304	381	242
	Torque peak limit i = 31[%]	141	193	207	270	156
P-0-0508	Commutation offset Resolver / EnDat	512				
	Commutation offset Hiperface	341				
P-0-0510	Rotor inertia					
	i = 21 without brake [kgm²]	0,000008	0,000023	0,000087	0,000234	0,000995
	i = 21 with brake [kgm²]	0,000015	0,000030	0,000095	0,000257	0,001170
	i = 31 without brake [kgm²]	0,000008	0,000023	0,000087	0,000233	0,000988
	i = 31 with brake [kgm²]	0,000015	0,000030	0,000095	0,000256	0,001163
P-0-4016	Direct-axis inductance of motor [mH]	13,8	15,3	6,3	6,3	1,2
P-0-4017	Quadrature-axis inductance of motor [mH]	13,8	15,3	6,3	6,3	1,2
P-0-4048	Stator resistance [Ohm]	61,10	44,20	9,20	4,50	0,36
S-0-0043	Velocity polarity parameter Resolver / EnDat / Hiperface	0111 / 0000 / 0000				
S-0-0055	Position polarities Resolver / EnDat / Hiperface	1111 / 0000 / 0000				
S-0-0085	Torque polarity parameter Resolver / EnDat / Hiperface	0111 / 0000 / 0000				
S-0-0092	Bipolar torque / force limit value i = 61 [%]	205	305	304	381	242
	Bipolar torque / force limit value i = 91 [%]	141	193	207	270	156
S-0-0106	Current loop proportional gain 1 [V/A]	55	65	20	27,5	5,3
S-0-0107	Current loop integral action time 1 [ms]	0,3	0,5	0,7	2,78	6,67
S-0-0109	Motor peak current i = 21 [Aeff]	1,2	2,4	7	13,7	37,1
	Motor peak current i = 31 [Aeff]	0,8	1,5	4,8	9,7	23,9
S-0-0111	Motor current at standstill [Aeff]	0,60	0,80	2,30	3,60	15,30
S-0-0113	Maximum motor speed [1/min]	7000	7000	6000	5000	4500
S-0-0116	Feedback 1 resolution Resolver / EnDat / Hiperface	1 / 512 / 1024	1 / 2048 / 1024			
S-0-0201	Motor warning temperature [°C]	130	130	130	130	130
S-0-0204	Motor shutdown temperature [°C]	145	145	145	145	145
S-0-0100	Velocity loop proportional gain [As/rad]	0.05	0.05	0.2	0.2	0.2
S-0-0101	Velocity loop integral action time [ms]	10	10	10	10	10
P-0-0004	Velocity loop smoothing time constant [µs]	250	250	250	250	250
P-0-0525[2]	Holding brake control word	100[2]	100[2]	100[2]	100[2]	100[2]
S-0-0206	Drive on delay time [ms]	12	25	25	35	50
S-0-0207	Drive off delay time [ms]	6	6	6	7	10
P-0-0540	Torque of holding brake [Nm]	0,8 / 0,4 (Resolver)	1,8	1,8	4	15

---

[2] In case of TPM without brake, the parameter P-0-0525 has to be set to 0.

6 Parameters TPMA 025 - 110 600V

Data for combinations not shown here are available on demand.

Code	Description	TPMA025	TPMA050	TPMA110
	Statorlength	15	15	60
S-0-0141	Motor type	TPMA025	TPMA050	TPMA110
P-0-4014	Type of motor	0	0	0
P-0-0001	Switching frequency [kHz]	8	8	8
P-0-0018	Number of pole pairs	6	6	6
P-0-0051	Torque constant [Nm/Aeff]	0,76	1,02	0,91
P-0-0074	Encoder type 1 (motor encoder)			
	Resolver / EnDat / Hiperface	10 / 8 / 4		
P-0-0109	Torque peak limit i = 110 [%]	304	381	271
	Torque peak limit i = 154 [%]	238	313	188
	Torque peak limit i = 220 [%]	160	197	126
P-0-0508	Commutation offset Resolver / EnDat	512		
	Commutation offset Hiperface	341		
P-0-0510	Rotor inertia			
	i =110 without brake [kgm²]	0,000089	0,000243	0,001032
	i =110 with brake [kgm²]	0,000098	0,000266	0,001208
	i =154 without brake [kgm²]	0,000087	0,000235	0,001000
	i =154 with brake [kgm²]	0,000096	0,000258	0,001175
	i =220 without brake [kgm²]	0,000087	0,000231	0,000984
	i =220 with brake [kgm²]	0,000095	0,000254	0,001159
P-0-4016	Direct-axis inductance of motor [mH]	6,3	6,3	1,2
P-0-4017	Quadrature-axis inductance of motor [mH]	6,3	6,3	1,2
P-0-4048	Stator resistance [Ohm]	9,20	4,50	0,36
S-0-0043	Velocity polarity parameter			
	Resolver / EnDat / Hiperface	0111 / 0000 / 0000		
S-0-0055	Position polarities			
	Resolver / EnDat / Hiperface	1111 / 0000 / 0000		
S-0-0085	Torque polarity parameter			
	Resolver / EnDat / Hiperface	0111 / 0000 / 0000		
S-0-0092	Bipolar torque / force limit value i = 110	304	381	271
	Bipolar torque / force limit value i = 154	238	313	188
	Bipolar torque / force limit value i = 110	160	197	126
S-0-0106	Current loop proportional gain 1 [V/A]	20	27,5	5,3
S-0-0107	Current loop integral action time 1 [ms]	0,7	2,78	6,67
S-0-0109	Motor peak current i= 110 [Aeff]	7	13,7	41,4
	Motor peak current i= 154 [Aeff]	5,5	11,3	28,8
	Motor peak current i= 220 [Aeff]	3,7	7,1	19,2
S-0-0111	Motor current at standstill [Aeff]	2,30	3,60	15,30
S-0-0113	Maximum motor speed [1/min]	6000	5000	4500
S-0-0116	Feedback 1 resolution			
	Resolver / EnDat / Hiperface	1 / 2048 / 1024		
S-0-0201	Motor warning temperature [°C]	130	130	130
S-0-0204	Motor shutdown temperature [°C]	145	145	145
S-0-0100	Velocity loop proportional gain [As/rad]	0.2	0.2	0.2
S-0-0101	Velocity loop integral action time [ms]	10	10	10
P-0-0004	Velocity loop smoothing time constant [µs]	250	250	250
P-0-0525[3]	Holding brake control word	100[3]	100[3]	100[3]
S-0-0206	Drive on delay time [ms]	25	35	50
S-0-0207	Drive off delay time [ms]	6	7	10
P-0-0540	Torque of holding brake [Nm]	1,8	4	15

[3] In case of TPM without brake, the parameter P-0-0525 has to be set to 0.

7   Temperature sensor monitoring of the TPM

The TPM is available with different types of temperature sensors
Please choose the fitting parameters according to your TPM out of the attached list.
The PTC can be used to shutdown the motor in case of over temperature.
With the KTY84-130 you can do an additional temperature measurement.

7.1   TPM with KTY 84-130

Code	Wert
P-0-512	3

7.2   TPM with PTC STM160

| Code	Wert
P-0-0512	100
P-0-0513 #0	20
P-0-0513 #1	30
P-0-0513 #2	40
P-0-0513 #3	50
P-0-0513 #4	60
P-0-0513 #5	70
P-0-0513 #6	80
P-0-0513 #7	90
P-0-0513 #8	100
P-0-0513 #9	110
P-0-0513 #10	120
P-0-0513 #11	130
P-0-0513 #12	140
P-0-0513 #13	150
P-0-0513 #14	160
P-0-0513 #15	200
P-0-0513 #16	250
P-0-0513 #17	425
P-0-0513 #18	940
P-0-0513 #19	2665
P-0-0513 #20	4000
P-0-0513 #21	4001
P-0-0513 #22	4002
P-0-0513 #23	4003
P-0-0513 #24	4004
P-0-0513 #25	4005
P-0-0513 #26	4006
P-0-0513 #27	4007

8 Connection schematic TPM / TPMA ⇔ IndraDrive

For detailed information about cable design and screening the documentation of the drive manufacturer has to be consulted.
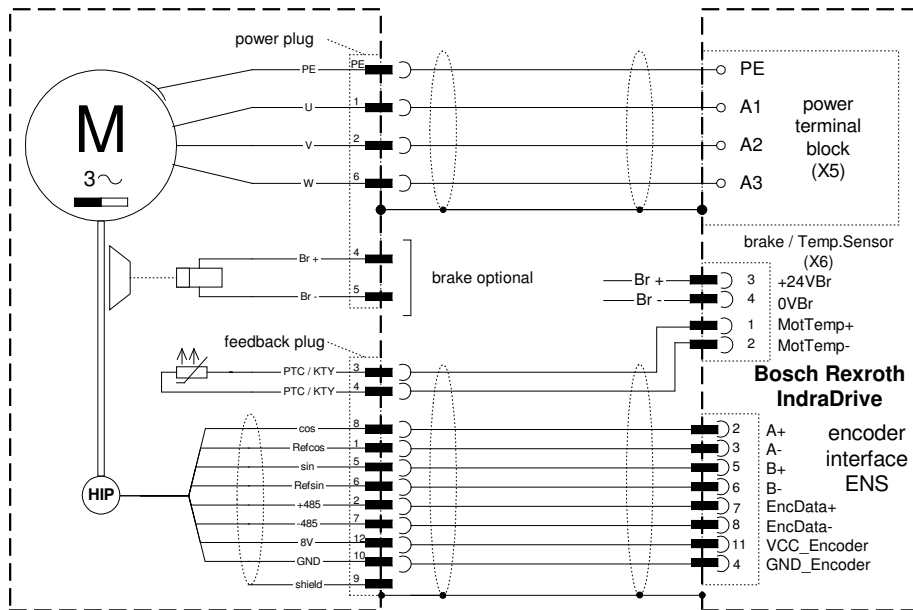
8.1 TPM / TPMA with resolver feedback
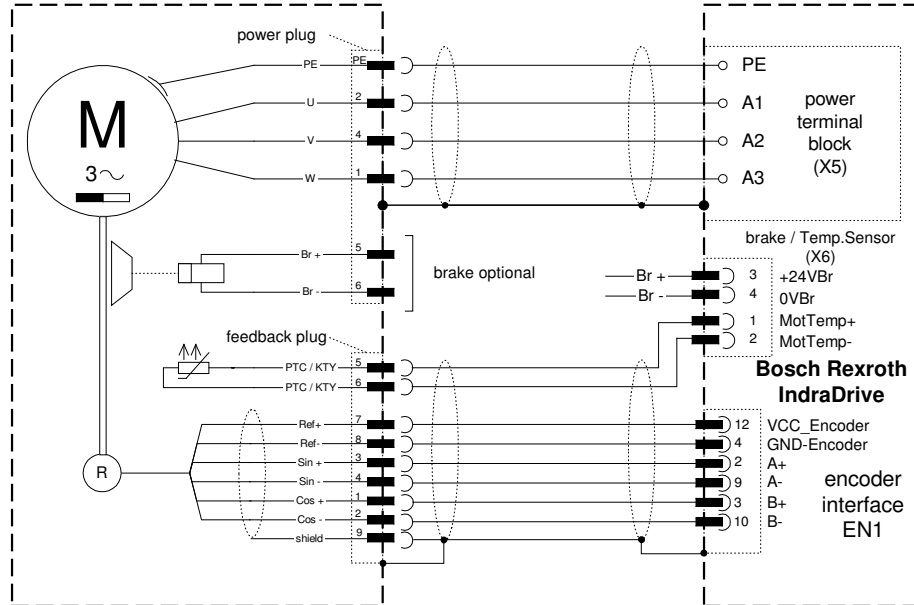
8.2 TPM / TPMA with absolute rotary encoder ECN 1113 / EQN 1125 / ECN 1313 / EQN 1325
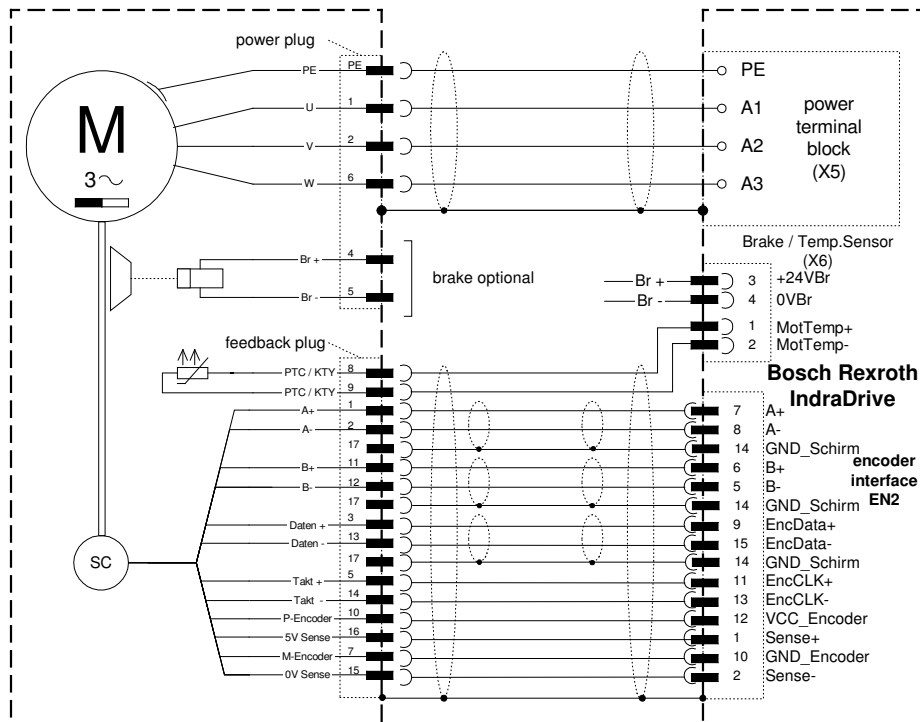
8.3   TPM / TPMA with absolute rotary encoder Hiperface SRS50 / SRM50

9 Diagnostic messages during initial start-up

During initial start-up faults may occur. Following diagnostic messages could appear with an correctly working TPM. For further investigations please consult the documentation from Bosch Rexroth.

Diagnostic message	Possible cause	Solution
F2028 Excessive deviation F8078 Velocity loop error F8079 Velocity limit S-0-0091 exceeded	Commutation angle not correct	Check wiring of motor and motor feedback. Verify that P-0-0508 was taken over correctly by the drive. If not please activate the commutation angle determination routine.
F2074 Absolute encoder out of window F2075 F2076	Initial start-up	Set absolute measurement
E2063 Velocity command value > limit S-0-0091	Speed command exceeds the value for bipolar limit in S-0-091	Adjust the value for S-0-0091 according your application. Verify the scaling of your application.
F2018 Device overtemperature shutdown F2019 Motor overtemperature shutdown F2021 Motor temperature monitor defective F2022 Device temperature monitor defective	Wrong parameterisation of temperature sensor	Reconfigure the parameters P-0-0512 and P-0-0513 according to your TPM.

10 Assignment TPM / TPMA ⇔ servo amplifier ⇔ cable set

10.1 TPM / TPMA with resolver feedback

Feed-back	size	i	320V	600V	5m L	5m S	10m L	10m S	15m L	15m S	20m L	20m S	25m L	25m S	30m L	30m S	40m L	40m S	50m L	50m S
Resolver	TPM 004	021, 031, 061, 091	-	HCS02.1E-W0012	4000 3876	4001 2031	4000 3877	4001 2656	4000 3878	4001 2657	4000 3879	4001 2658	4000 6169	4001 2658	4000 6093	4001 2660	4000 7678	4001 2661	4000 7452	4001 2662
			-																	
	TPM 010	021, 031, 061, 091	-	HCS02.1E-W0012																
			-																	
	TPM(A) 025	021, 031, 061, 091	-	HCS02.1E-W0012																
		110, 154, 220	-	HCS02.1E-W0012																
	TPM(A) 050	061	-	HCS02.1E-W0012																
		091, 110, 154, 220	-	HCS02.1E-W0028																
		021, 031	-	HCS02.1E-W0054	4000 6328		4000 6329		4000 6330		4000 6331		4000 7688		4000 7689		4000 7690		4000 7691	
	TPM(A) 110	021, 031, 061, 091	-	HCS02.1E-W0054																
		110, 154, 220	-	HCS02.1E-W0054																

Header grouping: **TPM type** (Feed-back, size, i), **Controller** (recommendation WMC [1]: 320V, 600V), **Article code for power (L) and feedback (S) cables** (5m, 10m, 15m, 20m, 25m, 30m, 40m, 50m — each L and S).

[1] WMC recommendation is based on use of a power stage with maximal PWM-frequency. Please refer to WMC or controller manufacture to select optimized controller size for the application. Possibly you

Power and Feedback cables for TPM with Resolver
all cable complete and for dynamic laying

power cable TPM 004-050	KABELL-TPM_-xxINDE-RES015-STG	structure power cable:	4 x 1,5mm2 + 2 x (2 x 1mm2), diameter 12,2mm, min. bending radius 122mm
power cable TPM 110	KABELL-TPM_-xxINDE-RES025-STG	structure power cable:	4 x 2,5mm2 + 2 x (2 x 1mm2), diameter 15,1mm, min. bending radius 151mm
feedback cable	KABELS-TPM_-xxBOID-RES000-STG	structure feedback cable:	5 x (2 x 0,25mm2) diameter 9,8mm; min bending radius 98mm

(xx = cable length)

WITTENSTEIN — motion control

10.2 TPM / TPMA with absolute encoder ECN 1113 / EQN 1125 / ECN 1313 / EQN 1325

Feedback	size	i	recommendation WMC [1] 320V	recommendation WMC [1] 600V	5m L	5m S	10m L	10m S	15m L	15m S	20m L	20m S	25m L	25m S	30m L	30m S	40m L	40m S	50m L	50m S
Absolute Single-/Multiturn feedback with EnDat Interface	TPM 004	021, 031, 061, 091	-	HCS02.1E-W0012	4000 5465	4001 2616	4000 5466	4001 2624	4000 5467	4001 2625	4000 5468	4001 2626	4000 6054	4001 2627	4000 7679	4001 2628	4000 7328	4001 2629	4000 5920	4001 2630
			-																	
	TPM 010	021, 031, 061, 091	-	HCS02.1E-W0012																
			-																	
	TPM(A) 025	021, 031, 061, 091	-	HCS02.1E-W0012																
		110, 154, 220	-	HCS02.1E-W0012																
	TPM(A) 050	061	-	HCS02.1E-W0012																
		091, 110, 154, 220	-	HCS02.1E-W0028																
		021, 031	-	HCS02.1E-W0054	4000 6830	4001 2616	4000 6831	4001 2624	4000 6832	4001 2625	4000 6833	4001 2626	4000 7692	4001 2627	4000 7693	4001 2628	4000 7694	4001 2629	4000 7695	4001 2630
	TPM(A) 110	021, 031, 061, 091	-	HCS02.1E-W0054																
		110, 154, 220	-	HCS02.1E-W0054																

[1] WMC recommendation is based on use of a power stage with maximal PWM-frequency. Please refer to WMC or controller manufacture to select optimized controller size for the application. Possibly you

Power and Feedback cables for TPM with EnDat absolute feedback ECN 1113 / EQN 1125 / ECN1313 / EQN1325
all cable complete and for dynamic laying

power cable TPM 004-050	KABELL-TPM_-xxSTD_-END015-STG	structure power cable:	4 x 1,5mm2 + 2 x 1mm2, diameter 12mm, min. bending radius 120mm
power cable TPM 110	KABELL-TPM_-xxSTD_-END025-STG	structure power cable:	4 x 2,5mm2 + 2 x 1mm2, diameter 15,1mm, min. bending radius 151mm
feedback cable	KABELS-TPM_-xxBOID-END000-STG	structure feedback cable:	3 x (2 x 0,14mm2) + 4 x 0,14mm2 + 4 x 0,25mm2 + 2 x 0,5mm2; diameter 10mm
			diameter 10mm; min. bending radius 100mm

(xx = cable length)

10.3 TPM / TPMA with absolute encoder SRS 50 / SRM 50

TPM type			Controller		Article code for power (L) and feedback (S) cables															
Feed-back		i	recommendation WMC [1]		5m		10m		15m		20m		25m		30m		40m		50m	
	size		320V	600V	L	S	L	S	L	S	L	S	L	S	L	S	L	S	L	S
Absolute Single-/Multiturn feedback with **Hiperface** Interface	TPM 004	021, 031, 061, 091	-	HCS02.1E-W0012	4000 5465	4001 1927	4000 5466	4001 1928	4000 5467	4001 1929	4000 5468	4001 1930	4000 6054	4001 1932	4000 7679	4001 1933	4000 7328	4001 1934	4000 5920	4001 1935
			-																		
	TPM 010	021, 031, 061, 091	-	HCS02.1E-W0012																
			-																		
	TPM(A) 025	021, 031, 061, 091	-	HCS02.1E-W0012																
		110, 154, 220	-	HCS02.1E-W0012																
	TPM(A) 050	061	-	HCS02.1E-W0012																
		091, 110, 154, 220	-	HCS02.1E-W0028																
		021, 031	-	HCS02.1E-W0054	4000 6830		4000 6831		4000 6832		4000 6833		4000 7692		4000 7693		4000 7694		4000 7695	
	TPM(A) 110	021, 031, 061, 091	-	HCS02.1E-W0054																
		110, 154, 220	-	HCS02.1E-W0054																

[1] WMC recommendation is based on use of a power stage with maximal PWM-frequency. Please refer to WMC or controller manufacture to select optimized controller size for the application. Possibly you

Power and Feedback cables for TPM with Stegmann Hiperface SRS 50 / SRM 50
all cable complete and for dynamic laying

power cable TPM 004-050	KABELL-TPM_-xxSTD_-END015-STG	structure power cable:	4 x 1,5mm2 + 2 x (2 x 1mm2), diameter 12,2mm, min. bending radius 122mm
power cable TPM 110	KABELL-TPM_-xxSTD_-END025-STG	structure power cable:	4 x 2,5mm2 + 2 x (2 x 1mm2), diameter 15,1mm, min. bending radius 151mm
feedback cable	KABELS-TPM_-xxBOID-HIP000-STG	structure feedback cable:	5 x (2 x 0,25mm2) diameter 9,8mm; min bending radius 98mm

(xx = cable length)