



Brushless DC Servomotors

Series

2232...BX4(S)

2250...BX4(S) 

# Technical Manual

EN

## Imprint

---

Version:  
7th edition, 15.04.2015

Copyright  
by Dr. Fritz Faulhaber GmbH & Co. KG  
Daimlerstr. 23/25 · 71101 Schönaich

All rights reserved, including translation rights.  
No part of this description may be duplicated, reproduced, stored in an information system or processed or transferred in any other form without prior express written permission of Dr. Fritz Faulhaber GmbH & Co. KG.

This technical manual has been prepared with care.  
Dr. Fritz Faulhaber GmbH & Co. KG cannot accept any liability for any errors in this technical manual or for the consequences of such errors. Equally, no liability can be accepted for direct or consequential damages resulting from improper use of the equipment.

The pertinent regulations regarding safety engineering and interference suppression as well as the specifications in this technical manual must be complied with when using the equipment.

Subject to change without notice.

The respective current version of this technical manual is available on FAULHABER's internet site:  
[www.faulhaber.com](http://www.faulhaber.com)

## Table of Contents

---

<b>1</b>	<b>Important Information</b>	<b>5</b>
1.1	Symbols used in this technical manual	5
1.2	Safety technicals	6
1.3	Documentation	6
1.4	Ambient conditions	7
1.5	Servicing/maintenance	8
1.6	Troubleshooting	8
<b>2</b>	<b>Description</b>	<b>9</b>
2.1	General product description	9
2.1.1	Motor without attachment	9
2.1.2	Motor with encoder IE3 or IE3 L	10
2.1.3	Motor with AES absolute encoder	11
2.1.4	Motor with SC speed controller	12
<b>3</b>	<b>Installation</b>	<b>13</b>
3.1	Assembly	13
3.2	EMC compatible installation	14
3.2.1	Description of the EMC measures	14
3.3	Connector pin assignment	16
3.3.1	Motor without attachment	16
3.3.2	Motor with encoder IE3 or IE3 L	17
3.3.3	Motor with AES absolute encoder	18
3.3.4	Motor with SC speed controller	19
3.4	Connection examples	20
3.4.1	Motor without attachment	20
3.4.2	Motor with encoder IE3	20
3.4.3	Motor with encoder IE3 L	21
3.4.4	Motor with AES absolute encoder	22
3.4.5	Motor with SC speed controller	23
<b>4</b>	<b>Functional Description</b>	<b>24</b>
4.1	Motor without attachment	24
4.1.1	Connection functions with digital Hall sensors (standard version)	24
4.1.2	Connection functions with analog Hall sensors (option 3692)	26
4.2	Motor with encoder IE3 or IE3 L	28
4.2.1	Connection functions	28
4.3	Motor with AES absolute encoder	32
4.3.1	Connection functions	32

## Table of Contents

---

4.4	Motor with SC speed controller	34
4.4.1	Connection functions	34
4.4.2	Configuration	36
4.4.3	Special configurations	38
4.4.4	Parameter settings	40
4.4.5	Technical information	42
<b>5</b>	<b>Operation</b>	<b>44</b>
5.1	Commissioning	44
<b>6</b>	<b>EC Product Safety Directives</b>	<b>45</b>
<b>7</b>	<b>Warranty</b>	<b>46</b>

# 1 Important Information

This technical manual describes the handling and technical features of FAULHABER's Series 22xx...BX4 brushless DC servomotors.

Series 22xx...BX4 drives can be optionally combined with integrated encoders, encoders with line drivers, absolute coders or speed controllers to form complete drive units.

- Please read through the complete technical manual before using the motor.
- Keep this technical manual in a safe place for later use.

The information given in this technical manual refers to the standard version of the motors. Please refer to any additional information sheet provided in the event of differences in information due to a customer-specific motor modification.

## 1.1 Symbols used in this technical manual

### **WARNING!**



### **Warning!**

*This pictogram with the wording "Warning!" indicates an imminent danger which can result in physical injuries.*

- ▶ *This arrow points out the appropriate action to take to prevent the imminent danger.*

### **CAUTION!**



### **Caution!**

*This pictogram with the wording "Caution!" indicates an imminent danger which can result in slight physical injuries or material damage.*

- ▶ *This arrow points out the appropriate precautions.*

### **REGULATION!**



### **Regulations, guidelines and directives**

*This pictogram with the wording "Regulation" indicates a statutory regulation, guideline or directive which must be observed in the respective context of the text.*

### **NOTE**



### **Note**

*This "Note" pictogram provides tips and recommendations for use and handling of the component.*

# 1 Important Information

## 1.2 Safety technicals

Observance of the following safety technicals is prerequisite for trouble-free and safe operation of the motor. Therefore, please carefully read through all the notes and follow them when using the motor.

### Intended use

The servomotor is designed as a drive for small mechanisms, as well as for continuously running and positioning applications, e.g. pump and scanner drives or in metering technology.

- External control electronics are required to operate the motors without integrated speed controllers.
- The motor contains magnetic and electromagnetic components. Any effects as well as the specific relevant national regulations must be taken into account when using the motor.
- The motor may not be used in environments where contact with water, chemicals and/or dust is possible or in potentially explosive atmospheres!
- The forces, torques and accelerations acting on the motor are limited.
- Please ask the manufacturer for information about individual use under special ambient conditions.

## 1.3 Documentation

The following table gives an overview of the documentation of the FAULHABER electronic products described in this technical manual:

Products Series	Data sheets										Technical manuals		
	2232...BX4	2232...BX4S	2232...BX4 mit Encoder	2232...BX4S mit Encoder	2232...BX4 SC	2232...BX4S SC	2250...BX4	2250...BX4S	2250...BX4 mit Encoder	2250...BX4S mit Encoder	2250...BX4 SC	2250...BX4S SC	BX4 22 mm (MA05016)
2232...BX4	X												X
2232...BX4S		X											X
2232...BX4 IE3			X										X
2232...BX4S IE3				X									X
2232...BX4 IE3 L			X										X
2232...BX4S IE3 L				X									X
2232...BX4 AES			X										X
2232...BX4S AES				X									X
2232...BX4 SC					X								X
2232...BX4S SC						X							X
2250...BX4							X						X
2250...BX4S								X					X
2250...BX4 IE3									X				X
2250...BX4S IE3										X			X
2250...BX4 IE3 L									X				X
2250...BX4S IE3 L										X			X
2250...BX4 AES									X				X
2250...BX4S AES										X			X
2250...BX4 SC											X		X
2250...BX4S SC												X	X

The documentation is available on request or from the FAULHABER internet site ([www.faulhaber.com](http://www.faulhaber.com)).

# 1 Important Information

---

## 1.4 Ambient conditions

### CAUTION!



#### **Shock loads**

*The noise emitted is increased and the life of the ball bearings and therefore of the servomotor becomes limited if they are exposed to impacts.*

- ▶ *The servomotor can still function if it is not exposed to higher shock loads than defined according to EN 60068-2-27.*
- ▶ *The servomotor may not be exposed to higher vibration stresses than defined according to EN 60068-2-6.*

### CAUTION!



#### **Risk of damage**

*If the servomotor is installed on the mounting flange, the mounting flange can be damaged by high radial loads or stresses on the servomotor or by screws tightened with excessive torque.*

- ▶ *Do not load the servomotor at the rear end with a radial force greater than 30 N.*
- ▶ *Tighten the screws with maximum 50 Ncm. Note the strength of the screws!*

### NOTE



#### **Service life**

*The full life is reached if the servomotor is not exposed to shock or vibration loads.*

### CAUTION!



#### **Risk of damage**

*The ribbon cables may be damaged if the static or dynamic load is too high.*

**The following applies to cables with contact spacing 1.27 AWG28:**

- ▶ *The tension exerted on the cable must not exceed 30 N in each direction. If the cable is exposed to constant tensile loads the limit is 17 N.*
- ▶ *In case of frequent bending, the recommended minimum bending radius is 10 mm. The possible number of bending cycles increases with increasing bending radius.*
- ▶ *If the radii are small the cable may not be bent several times as otherwise the Litz wires will break. The bending radii if laid once must be larger than 1.2 mm.*
- ▶ *The cable may not be bent at temperatures < -10 °C.*

# 1 Important Information

---

## 1.5 Servicing / maintenance

The servomotor is designed to be maintenance free. No maintenance measures are necessary.

## 1.6 Troubleshooting

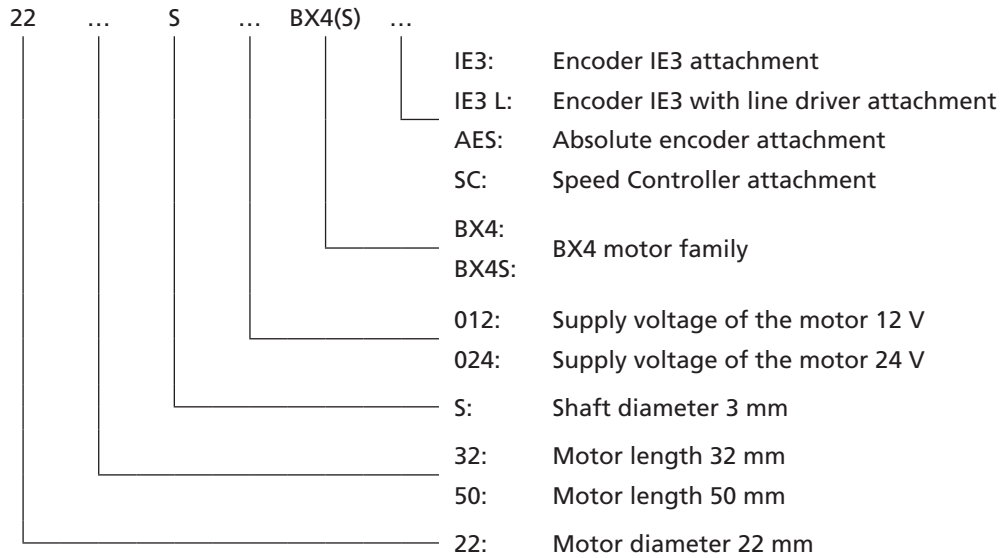
The servomotor is designed to be fault-free, provided the parameters given in this technical manual are complied with. If malfunctions occur during proper intended use, please contact your responsible partner.



## 2 Description

### 2.1 General product description

#### Product information



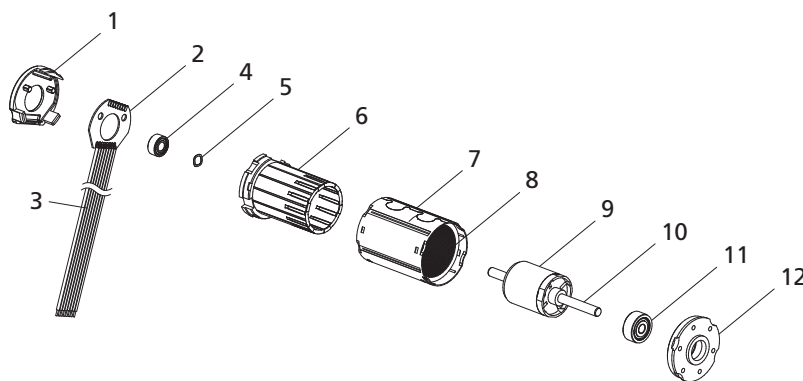
#### 2.1.1 Motor without attachment

The servomotor is an electronically commuted (brushless) DC motor. Compared to mechanically commuted electric motors, its main outstanding feature is a much longer life.

The motor is based on the self-supporting coil technology, FAULHABER system, and essentially consists of a three-phase winding (stator) and a four-pole permanent magnet (rotor). The commutation takes place via an additional external control.

The rotor position is registered by 3 digital or optionally analog Hall sensors.

FAULHABER controls SC 2804/SC 5008 or MCBL 3006 (in conjunction with analog Hall sensors) are recommended for operating the servomotor.



- |                      |                             |                               |
|----------------------|-----------------------------|-------------------------------|
| 1 Cover              | 5 Spring                    | 9 Rotor with permanent magnet |
| 2 Adapter board      | 6 Winding with Hall sensors | 10 Shaft                      |
| 3 Ribbon cable       | 7 Housing                   | 11 Front motor bearing        |
| 4 Rear motor bearing | 8 Steel yoke                | 12 Mounting flange            |

## 2 Description

### 2.1 General product description

#### 2.1.2 Motor with encoder IE3 or IE3 L

In this option, the servomotor described in [Chapter 2.1.1](#) has an encoder with 3 output channels (IE3). A permanent magnet on the shaft generates a moving magnetic field which is measured and further processed by means of a rotary encoder. At the encoder's outputs there are two rectangular signals, phase-shifted by 90°, with up to 1024 pulses and one index pulse per motor.

The encoder is available with different pulse rates (32, 64, 128, 256, 512 or 1024 pulses/revolution). The pulse rate is included in the motor designation. Further resolutions of 1 – 127 pulses are available on request.

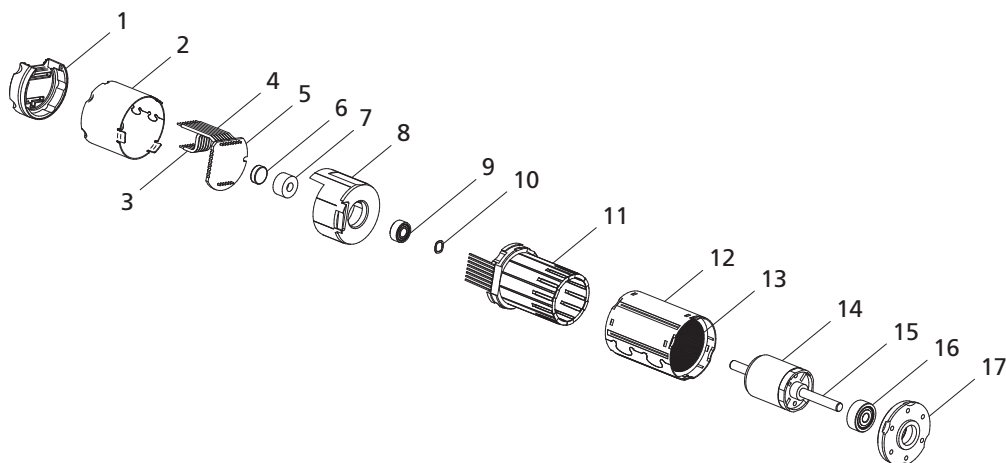
#### Example

Motor: 2232 ... BX45 IE3-128 L

Features: Motor 2232 ... BX45 with encoder, 128 pulses/rotation, line driver

#### Line driver

Encoders with an "L" in the encoder designation have differential encoder signal outputs in accordance with TIA 422. Therefore, common-mode interferences are suppressed and longer supply connectors are enabled. These three differential signals must be joined together again on the connection side with a receiver module. The precise function is described in [Chapter 4.2 "Motor with encoder IE3 or IE3 L"](#).



- |                      |                                |
|----------------------|--------------------------------|
| 1 Cover              | 10 Spring                      |
| 2 Built-on housing   | 11 Winding with Hall sensors   |
| 3 Ribbon cable 1     | 12 Housing                     |
| 4 Ribbon cable 2     | 13 Steel yoke                  |
| 5 Encoder board      | 14 Rotor with permanent magnet |
| 6 Sensor magnet      | 15 Shaft                       |
| 7 Magnet holder      | 16 Front motor bearing         |
| 8 Mounting flange    | 17 Mounting flange             |
| 9 Rear motor bearing |                                |

## 2 Description

### 2.1 General product description

#### 2.1.3 Motor with AES absolute encoder

In this option, the servomotor described in [Chapter 2.1.1](#) has an absolute encoder with serial interface.

A permanent magnet on the shaft generates a moving magnetic field which is measured and further processed by means of a single chip rotary encoder.

Absolute angle information with a resolution of 4096 steps is available at the outputs, which can be queried via a serial interface (SSI). Absolute means that each shaft position within a revolution is assigned a unique angle value. This is available immediately after switching on.

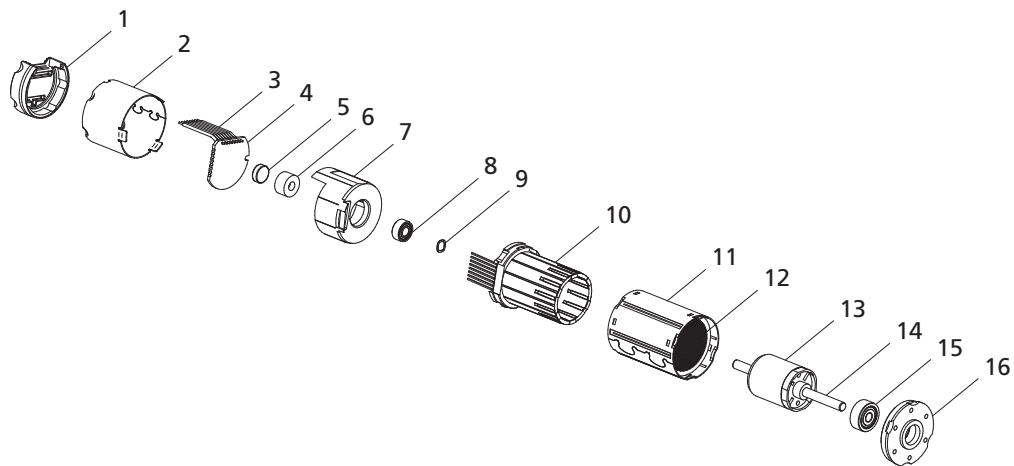
The absolute encoder is optimally suited to commutation, speed and position control. It can also be used for sinus commutation. The advantage in this case is that the motor is run more efficiently and torque ripple is minimised.

It is connected via only one ribbon cable (unlike the version with incremental encoder).

#### Example

Motor: 2232 ... BX4 AES-4096

Features: Motor 2232 ... BX4 with absolute encoder, resolution 4096 steps/revolution



- 1 Cover
- 2 Built-on housing
- 3 Ribbon cable
- 4 Encoder board
- 5 Sensor magnet
- 6 Magnet holder
- 7 Mounting flange
- 8 Rear motor bearing

- 9 Spring
- 10 Winding with Hall sensors
- 11 Housing
- 12 Steel yoke
- 13 Rotor with permanent magnet
- 14 Shaft
- 15 Front motor bearing
- 16 Mounting flange

## 2 Description

### 2.1 General product description

#### 2.1.4 Motor with SC speed controller

In this option, the servomotor described in [Chapter 2.1.1](#) has integrated commutation electronics (SC speed controller), which provides diverse motor control possibilities.

The motor offers the following functions:

- Control of the speed through set value input or control of the speed through the motor voltage.
- Switchover of direction of rotation via switch input.
- Reading out the speed signal via the frequency output.

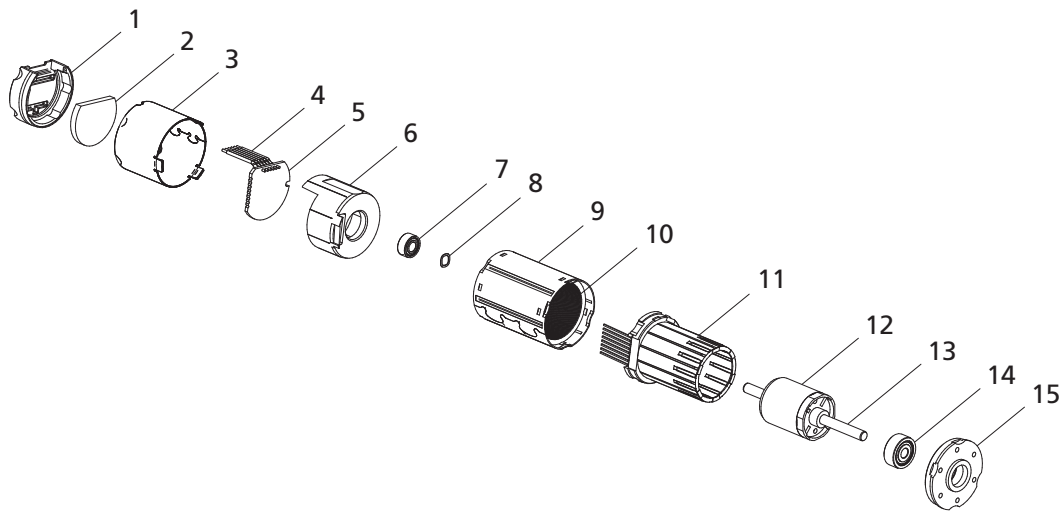
#### CAUTION!



#### Risk of damage

Switching over the motor's direction of rotation (reversing duty) too quickly can cause damage.

- ▶ Do not use the speed controller for reversing duty.



- 1 Cover
- 2 Heat transfer pad
- 3 Built-on housing
- 4 Ribbon cable
- 5 Controller board
- 6 Mounting flange
- 7 Rear motor bearing
- 8 Spring

- 9 Housing
- 10 Steel yoke
- 11 Winding with Hall sensors
- 12 Rotor with permanent magnet
- 13 Shaft
- 14 Front motor bearing
- 15 Mounting flange

## 3 Installation

### 3.1 Assembly

The servomotor must be installed according to certain specifications to prevent malfunctions and damage.

**CAUTION!**



**Material damage**

*Incorrect installation or installation with the wrong fixing materials can cause irreparable damage to the motor's function and/or damage the motor.*

- ▶ Observe the following assembly technicals.

**Use environment**

Depending on its use, the servomotor can get very hot. Appropriate heat dissipation possibilities must be provided.

**Shaft load**

When pressing parts on the motor shaft it must be held against on the opposite side. Otherwise the maximum allowable load values (axial at a standstill) must be noted and observed.

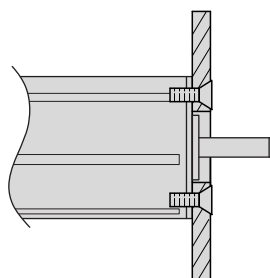
**Mounting flange**

When fixing the servomotor to the front flange, the screws must be locked as they can loosen at high temperatures. The maximum length of the fixing screws must be noted and observed as otherwise the motor will be destroyed.

**Do not exceed the maximum allowable screw-in depth as given in the product data sheet.**

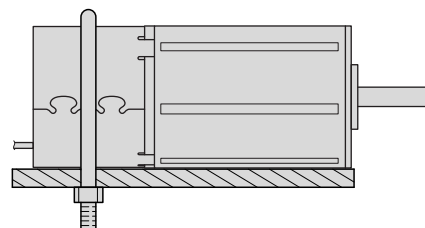
**Right**

The motor is fixed by the screws on the mounting flange.



**Wrong**

The motor is securely clamped to the attachment with a U-bolt.



**Electrical connection**

It is necessary to ensure that the ribbon cable is laid without risk of damage during installation and operation, e.g. through chafing, squeezing or too small bending radii. The maximum load of the cable must be noted and observed (see [Chapter 1.4 "Ambient conditions"](#)).

Detailed information on connecting the products described in these technicals are given in the relevant data sheets on FAULHABER's internet site ([www.faulhaber.com](http://www.faulhaber.com)).

## 3 Installation

### 3.2 EMC compatible installation

**CAUTION!**



**Length of the connection leads**

The maximum length of the connection leads is limited.

- ▶ All connection leads may not exceed a length of 3 m.

Optimisation of performance with respect to emission and immunity requires the additional EMC measures:

- Ensuring the necessary immunity in industrial uses can require use of an EMC suppressor circuit.

Motor designation	Use environment	Interference type	Action
Motor without attachment	Industrial environment		
Motor with SC speed controller	Industrial environment	Immunity	EMC suppressor circuit

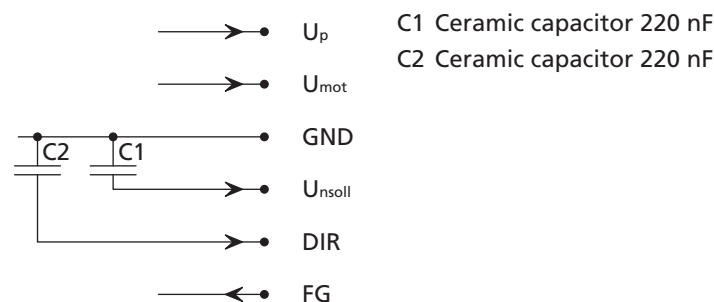
This table shows which additional EMC measures can be implemented to optimise the behaviour of the equipment in the intended environment with regard to immunity.

The units are intended for industrial use only. If the devices are used in the home, in business or in commerce or in a small business, appropriate measures must be taken to ensure that the emitted interference is below the permitted limits!

#### 3.2.1 Description of the EMC measures

##### The EMC suppressor circuit (motor with Speed Controller SC only)

Circuit diagram 1



**NOTE**



**Capacitor C1:**

If the ceramic capacitor C1 is used, malfunctions can occur in PWM<sub>target</sub> operating mode.

- ▶ Use signal source with low internal resistance in PWM<sub>target</sub> operating mode.

**NOTE**



**Capacitor C2:**

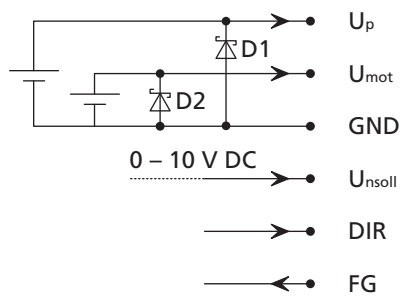
If using the ceramic capacitor C2, a firmware update with the Motion Manager PC firmware may no longer be possible.

- ▶ Remove the C2 capacitor when updating the firmware.

## 3 Installation

### 3.2 EMC compatible installation

Circuit diagram 2



Separate suppressor diodes (D1, D2) for  $U_p$  and  $U_{mot}$  if they have separate supply voltages.

If only one supply voltage is used, (bridge between  $U_p$  and  $U_{mot}$ ), one suppressor diode (D1) is sufficient. D1 and D2 e.g. P6KE33A from STMicroelectronics

**NOTE**



**Exceptions:**

*It may not be necessary to implement the additional EMC measures named. If the motor is fed e.g. from a CE-conforming power supply unit, the EMC suppressor circuit can be dispensable. In this case the power supply unit takes on the function of the EMC suppressor circuit according to circuit diagram 2.*

**NOTE**



**Motor without attachment:**

*A control, e.g. FAULHABER's SC2804, is recommended for operation of the servomotor.*

## 3 Installation

### 3.3 Connector pin assignment

#### 3.3.1 Motor without attachment

The servo motor is equipped, as a standard, with an eight-core ribbon cable for the power supply to the motor phases and sensor technology as well as for transfer of the digital (standard) or analog (option 3692) Hall sensor signals.

For more detailed information on the hall sensor signals, see [Chapter 4.1 "Motor without attachment"](#).

#### CAUTION!



#### Electronic damage /ESD protection

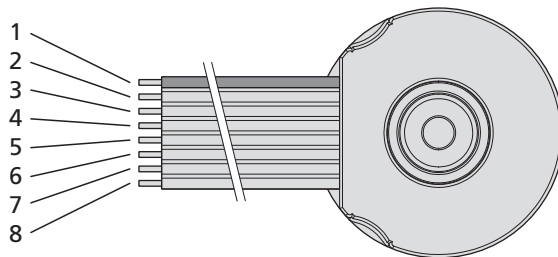
*Electrostatic discharges at the connection pin assignment of the ribbon cable can result in irreparable damage to the motor.*

- ▶ *It may only be processed in ESD protected workplaces.*

*Incorrect connection of the cores can cause damage to or destruction of the electronics.*

- ▶ *Connect the ribbon cable in accordance with the connector pin assignment, see table.*

#### Connection pin assignment of the ribbon cable



Core	Function
1 (red)	Phase C
2	Phase B
3	Phase A
4	GND
5	U <sub>DD</sub>
6	Hall sensor C
7	Hall sensor B
8	Hall sensor A



## 3 Installation

### 3.3 Connector pin assignment

#### 3.3.2 Motor with encoder IE3 or IE3 L

Apart from the eight-core connection cable for supplying the motor described in [Chapter 3.3.1](#), the servomotor with encoder also has a six-core ribbon cable (ten-core in encoders with line driver) for the encoder's connections.

**CAUTION!**



**Electronic damage /ESD protection**

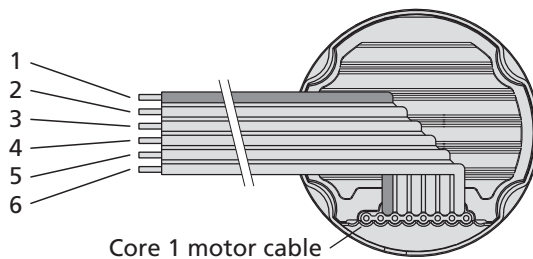
*Electrostatic discharges at the connection pin assignment of the ribbon cable can result in irreparable damage to the motor.*

► *It may only be processed in ESD protected workplaces.*

*Incorrect connection of the cores can cause damage to or destruction of the electronics.*

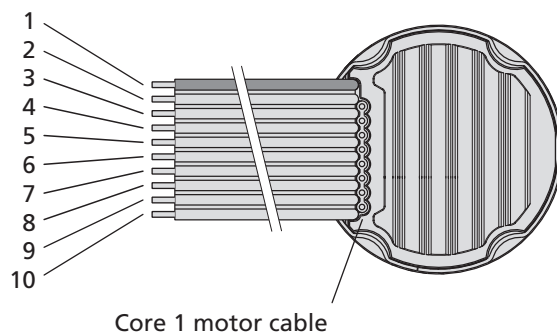
► *Connect the ribbon cable in accordance with the connector pin assignment, see table.*

#### Connection pin assignment of the ribbon cable for encoders without line driver (IE3)



Core	Function
1 (red)	n.c.
2	Channel I (index)
3	GND Enc
4	UDD Enc
5	Channel B
6	Channel A

#### Connection pin assignment of the ribbon cable for encoders with line driver (IE3 L)



Core	Function
1 (red)	n.c.
2	UDD Enc
3	GND Enc
4	n.c.
5	Channel $\bar{A}$
6	Channel A
7	Channel $\bar{B}$
8	Channel B
9	Channel $\bar{I}$ (index)
10	Channel I (index)

## 3 Installation

### 3.3 Connector pin assignment

#### 3.3.3 Motor with AES absolute encoder

The servomotor with AES absolute encoder is equipped, as a standard, with an eight-core ribbon cable for the power supply to the phases and encoder, and for signal transfer of the angle information via a serial interface (SSI).

**CAUTION!**



**Electronic damage /ESD protection**

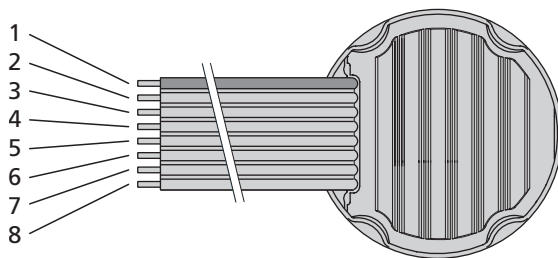
*Electrostatic discharges at the connection pin assignment of the ribbon cable can result in irreparable damage to the motor.*

- ▶ *It may only be processed in ESD protected workplaces.*

*Incorrect connection of the cores can cause damage to or destruction of the electronics.*

- ▶ *Connect the ribbon cable in accordance with the connector pin assignment, see table.*

**Connection pin assignment of the ribbon cable for absolute encoder**



Core	Function
1 (red)	Phase C
2	Phase B
3	Phase A
4	GND <sub>Enc</sub>
5	U <sub>DD Enc</sub>
6	CLK
7	Res.
8	DATA

## 3 Installation

### 3.3 Connector pin assignment

#### 3.3.4 Motor with SC speed controller

The servomotor with integrated SC speed controller is equipped with a six-core ribbon cable for the power supply and control of the motor functions.

**CAUTION!**



**Electronic damage /ESD protection**

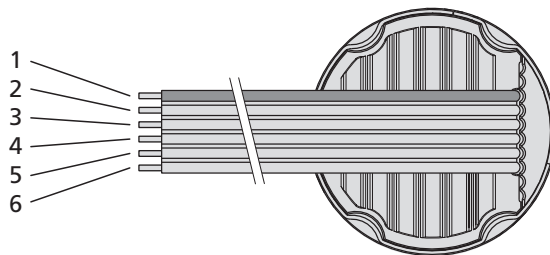
*Electrostatic discharges at the connection pin assignment of the ribbon cable can result in irreparable damage to the motor.*

► *It may only be processed in ESD protected workplaces.*

*Incorrect connection of the cores can cause damage to or destruction of the electronics.*

► *Connect the ribbon cable in accordance with the connector pin assignment, see table.*

**Connection pin assignment of the ribbon cable for speed controller**

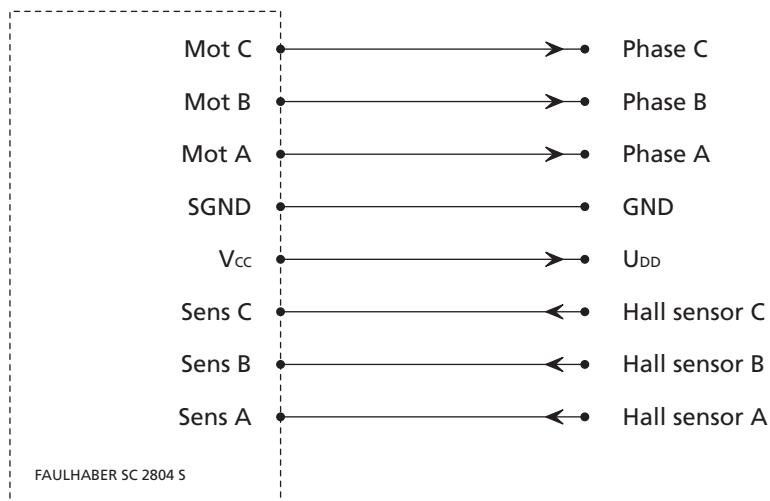


Core	Function
1 (red)	U <sub>P</sub>
2	U <sub>mot</sub>
3	GND
4	U <sub>nsoll</sub>
5	DIR
6	FG

## 3 Installation

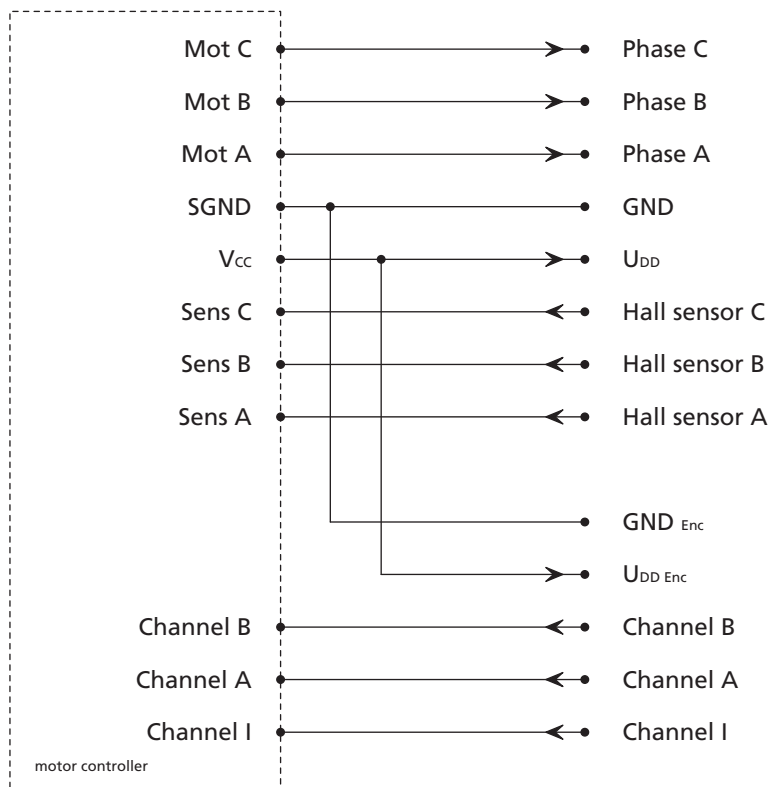
### 3.4 Connection examples

#### 3.4.1 Motor without attachment



In the example the servomotor is operated with the FAULHABER control SC 2804 S.

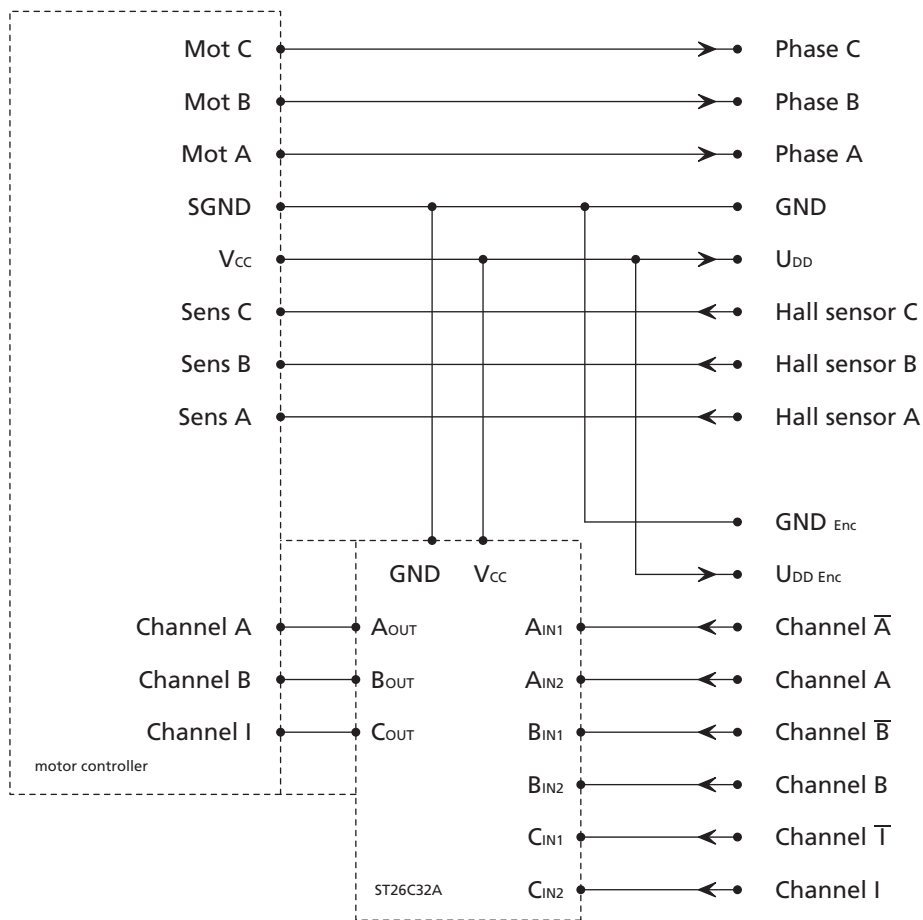
#### 3.4.2 Motor with encoder IE3



## 3 Installation

### 3.4 Connection examples

#### 3.4.3 Motor with encoder IE3 L

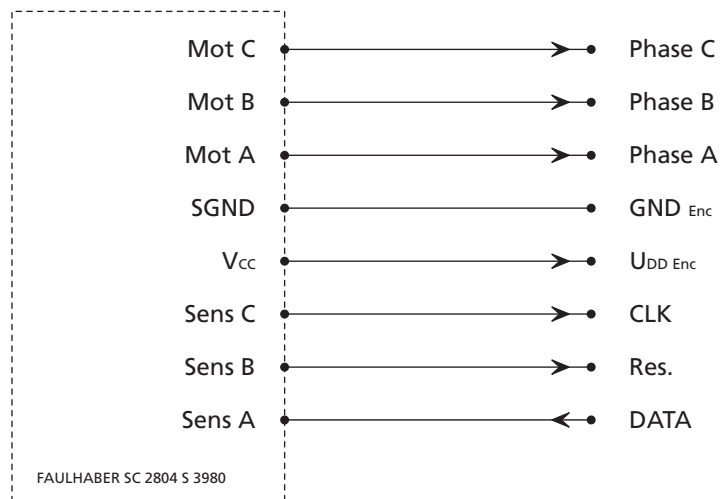


The differential encoder signals are joined with a TIA-422 compatible receiver module on the connection side (here: ST26C32A).

## 3 Installation

### 3.4 Connection examples

#### 3.4.4 Motor with AES absolute encoder



In the example the servomotor is operated with the FAULHABER control SC 2804 S 3980.

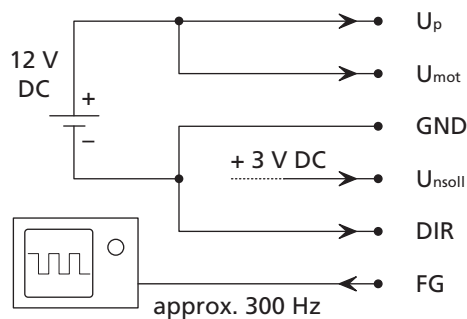
## 3 Installation

### 3.4 Connection examples

#### 3.4.5 Motor with SC speed controller

Two examples are given and are intended to clearly explain the operating modes of the servomotor with SC Speed controller. The figures given refer to a motor with a nominal voltage of 12 V.

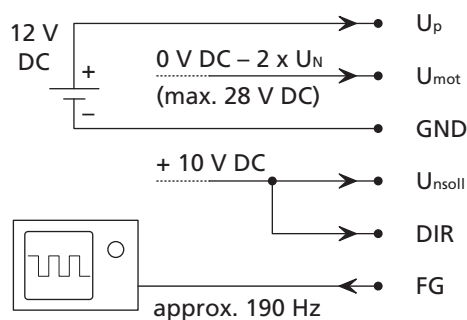
##### Electronic speed control



The motor rotated anti-clockwise with approx. 3000 rpm, the speed is controlled electronically. Command source 3 V at 1000 rpm/V corresponds to a target velocity of 3000 rpm.

The actual speed at FG is: 300 Hz/6 pulses per revolution \* 60 s = 3000 rpm. Rotational direction command (anti-clockwise) made by 0 V at DIR.

##### External speed control



The motor rotates e.g. with 1900 rpm in a clockwise direction, the speed is controlled by the motor voltage ( $U_{mot}$ ). Approx. 190 Hz is measured at the frequency output (FG).

190 pulses/sec = 31.66 rev/sec,

31.66 rev/sec = 1900 rpm.

#### NOTE



The minimum and maximum supply voltage must be noted and observed. See [Chapter 3.3.4 "Motor with SC speed controller"](#).

## 4 Functional Description

### 4.1 Motor without attachment



#### 4.1.1 Connection functions with digital Hall sensors (standard version)

The servomotor requires an external control for operations and has the connection options listed in [Chapter 3](#).

##### Phase C to Phase A (core 1 – 3)

The rotating field required to operate the motor is applied to phases C to A.

Voltage range: 0 V AC to  $U_{\max}$ .

The following limits must be adhered to for  $U_{\max}$ :

- Note and observe limit speed according to product data sheet.
- $U_{\max} < 50$  V AC (below the Low Voltage Directive).

#### CAUTION!



##### Harmonic components

*When the servomotor is operated with block commutation or PWM, harmonic components can arise, as a result of which the emission behaviour of the motor can worsen.*

- ▶ Ensured operation of the motor within the EMC requires a harmonic-free rotating field, or the suggested FAULHABER control. See [Chapter 3.4 "Connection examples"](#).

##### GND (core 4)

Joint ground of the Hall sensors.

##### $U_{DD}$ (core 5)

Supply voltage of the Hall sensors.

Voltage range: 2.2 ... 18 V DC.

Input current: < 18 mA.

##### Output signals Hall sensor C to Hall sensor A (core 6 – 8)

Signal output of the Hall sensors.

Voltage range: 0.1 V DC ...  $U_{DD}$ .

Output current: < 25 mA.

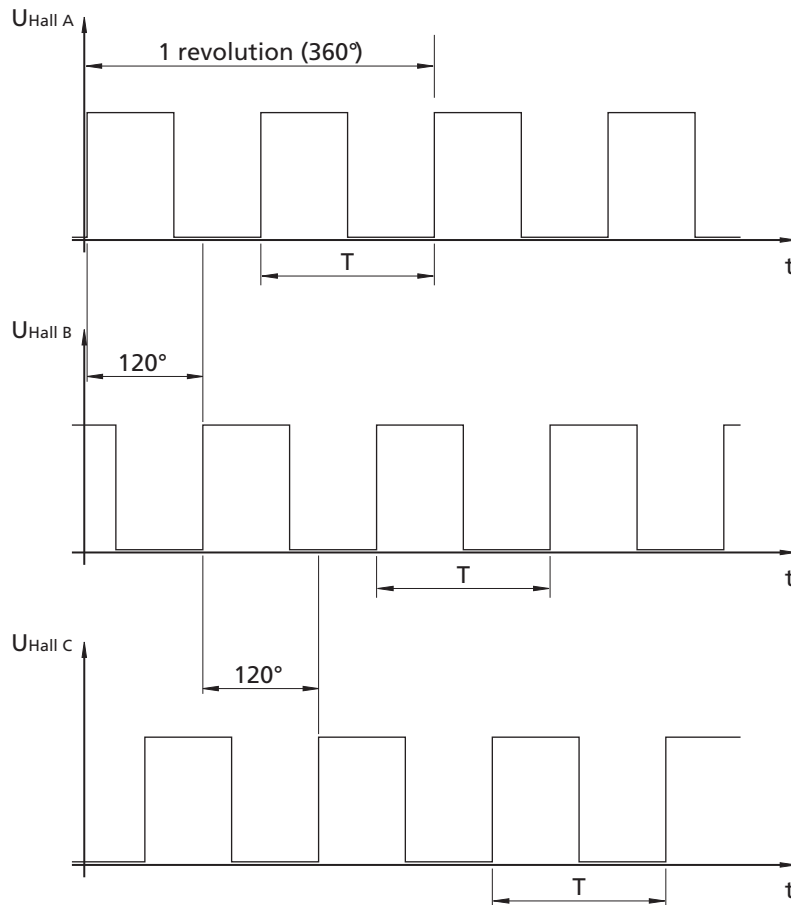
The output current results from the applied pull-up voltage and the pull-up resistance used.

Signal setup: The Hall signals are 120° out of phase with each other according to the phases. Due to the 4-pole version, the switching frequency is twice as high as the speed.



## 4 Functional Description

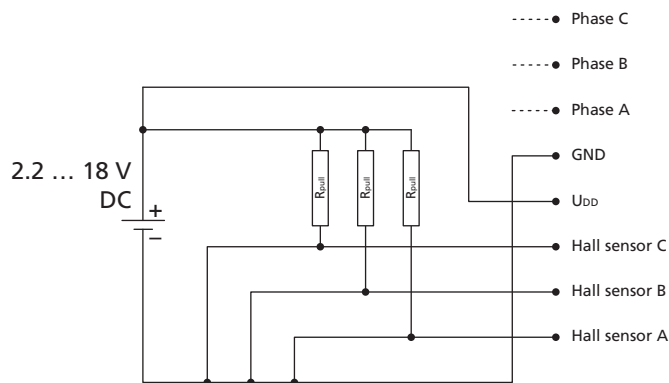
### 4.1 Motor without attachment



**NOTE**



The outputs of the Hall sensors are designed as open collectors. Therefore, pull-up resistances are required for operation.



■ R<sub>pull</sub>: ≥ 820 Ω

## 4 Functional Description

### 4.1 Motor without attachment

#### 4.1.2 Connection functions with analog Hall sensors (option 3692)

The servomotor requires an external control for operations and has the connection options listed in [Chapter 3](#).

##### Phase C to Phase A (core 1 – 3)

The rotating field required to operate the motor is applied to phases C to A.

Voltage range: 0 V AC to  $U_{\max}$ .

The following limits must be adhered to for  $U_{\max}$ :

- Note and observe limit speed according to product data sheet.
- $U_{\max} < 50$  V AC (below the Low Voltage Directive).

#### CAUTION!



##### Harmonic components

*When the servomotor is operated with block commutation or PWM, harmonic components can arise, as a result of which the emission behaviour of the motor can worsen.*

- ▶ Ensured operation of the motor within the EMC requires a harmonic-free rotating field, or the suggested FAULHABER control. See [Chapter 3.4 "Connection examples"](#).

##### GND (core 4)

Joint ground of the Hall sensors.

##### $U_{DD}$ (core 5)

Supply voltage of the Hall sensors.

Voltage range: 4.5 ... 5.5 V DC.

Input current: < 18 mA.

##### Output signals Hall sensor C to Hall sensor A (core 6 – 8)

Signal output of the Hall sensors.

Maximum voltage range: 0 V DC ...  $U_{DD}$ .

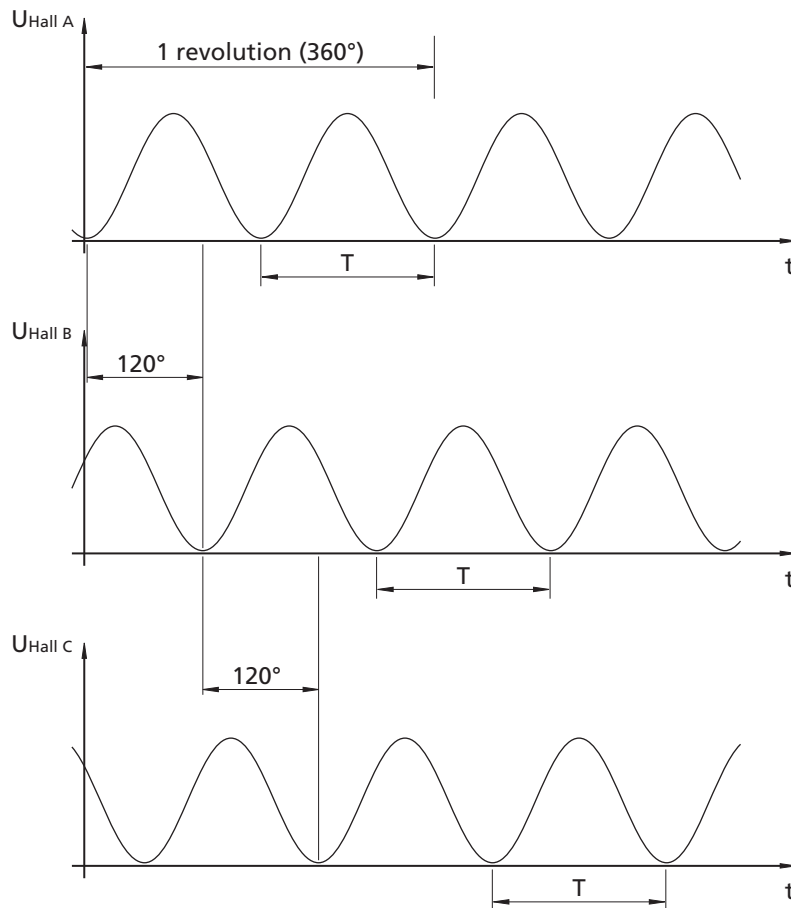
Typical voltage range:  $2.5 \pm 1.5$  V DC

Output current  $I_{A, \max}$ : 1 mA.

Signal setup: The Hall signals are 120° out of phase with each other according to the phases. Due to the 4-pole version, the switching frequency is twice as high as the speed.

## 4 Functional Description

### 4.1 Motor without attachment

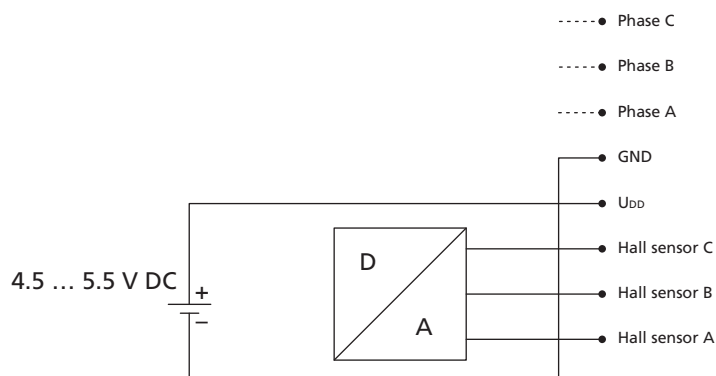


**NOTE**



The internal resistance of the decoder circuit should not exceed  $5\text{ k}\Omega$ .  
Filtering of the analog signals is recommended.

#### Wiring example



## 4 Functional Description

### 4.2 Motor with encoder IE3 or IE3 L

#### 4.2.1 Connection functions

In addition to the connection functions described in [Chapter 4.1 "Motor without attachment"](#), the servomotor with encoder also has a six-core ribbon cable (AWG28), ten core for encoders with line driver, which provides the encoder connection functions described here.

#### NOTE



*For the motor with IE3-512 and IE3-1024, the applicable Hall sensor supply differs from [Chapter 4.1](#) (4.5 ... 5.5 V DC;  $U_{DD} = U_{DD\ Enc}$ ). The outputs of the Hall sensors are implemented here as push-pull (CMOS and TTL compatible). Output current: max. 4 mA.*

#### Encoder without line driver

##### Channel I (core 2)

Output signal index signal.

Pulse rate: 1 pulse / revolution.

##### GND Enc (core 3)

Ground connection for the encoder.

##### $U_{DD\ Enc}$ (core 4)

Supply voltage for the encoder.

Voltage range: 4,5 ... 5,5 V DC.

IE3-32/64/128/256: Encoder and Hall sensors supply isolated ( $U_{DD} \neq U_{DD\ Enc}$ ).

IE3-512/1024: Encoder and Hall sensors supply connected ( $U_{DD} = U_{DD\ Enc}$ ).

##### Channel B (core 5)

Output signal B of the pulse generator, 90° offset from Channel A, COMES and TTL compatible.

Pulse rate (depending on the encoder setup): 32, 64, 128, 256, 512 or 1024 pulses/revolution.

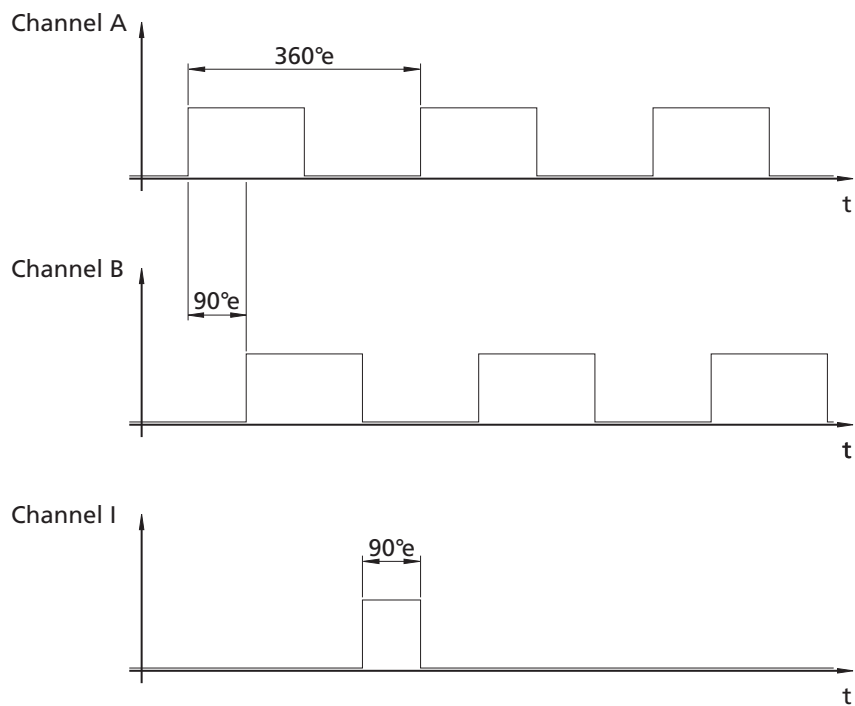
##### Channel A (core 6)

Output signal of the pulse generator, COMES and TTL compatible.

Pulse rate (depending on the encoder setup): 32, 64, 128, 256, 512 or 1024 pulses/revolution.

## 4 Functional Description

### 4.2 Motor with encoder IE3 or IE3 L



The display of the signals and phase displacement relates to a clockwise rotating motor (intended for output).

## 4 Functional Description

---

### 4.2 Motor with encoder IE3 or IE3 L

#### Encoder with line driver

In addition to the output signals Channel A, Channel B and Channel I, the encoder with line driver also provides the inverted signals Channel not A, Channel not B and Channel not I. These three differential signals must be joined together again on the connection side with a receiver module (e.g. ST26C32A from STM).

This symmetrical interface according to TIA-422 standard enables suppression of common mode interference and also enables longer supply conductors.

#### $U_{DD\ Enc}$ (core 2)

Supply voltage for the encoder, isolated from the motor.

Voltage range: 4.5 ... 5.5 V DC.

#### $GND_{Enc}$ (core 3)

Ground connection for the encoder, isolated from the motor.

#### Channel $\bar{A}$ (core 5)

Inverted output signal A of the pulse generator, TIA-422 compatible.

Pulse rate (depending on the encoder setup): 32, 64, 128, 256, 512 or 1024 pulses/revolution.

#### Channel A (core 6)

Output signal A of the pulse generator, TIA-422 compatible.

Pulse rate (depending on the encoder setup): 32, 64, 128, 256, 512 or 1024 pulses/revolution.

#### Channel $\bar{B}$ (core 7)

Inverted output signal B of the pulse generator, 90°e offset to channel A, TIA-422 compatible.

Pulse rate (depending on the encoder setup): 32, 64, 128, 256, 512 or 1024 pulses/revolution.

#### Channel B (core 8)

Output signal B of the pulse generator, 90°e offset to channel A, TIA-422 compatible.

Pulse rate (depending on the encoder setup): 32, 64, 128, 256, 512 or 1024 pulses/revolution.

#### Channel I (core 9)

Inverted output signal index signal.

Pulse rate: 1 pulse /revolution.

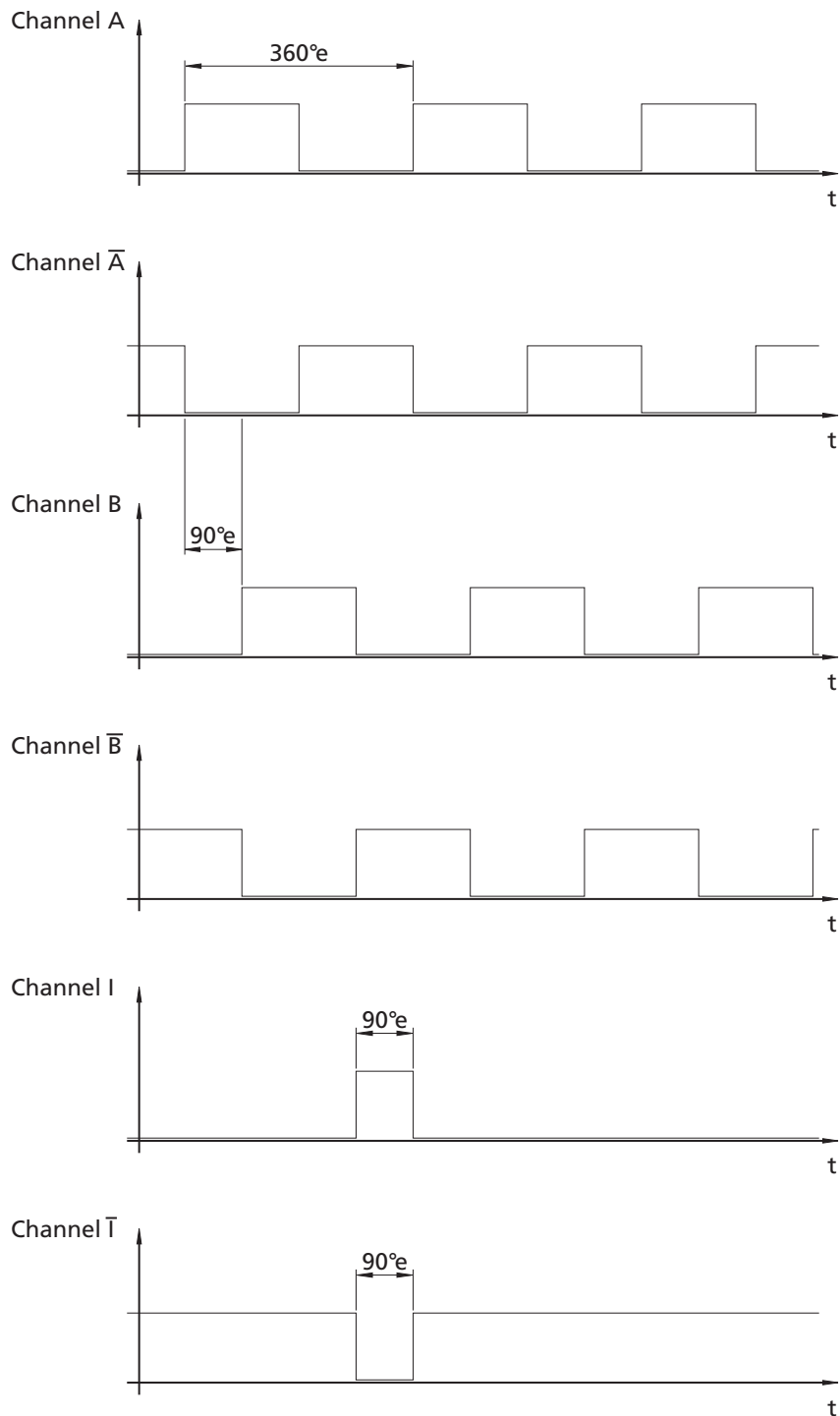
#### Channel $\bar{I}$ (core 10)

Output signal index signal.

Pulse rate: 1 pulse /revolution.

## 4 Functional Description

### 4.2 Motor with encoder IE3 or IE3 L



The display of the signals and phase displacement relates to a clockwise rotating motor (intended for output).

## 4 Functional Description

### 4.3 Motor with AES absolute encoder

#### 4.3.1 Connection functions

The servomotor with AES absolute encoder requires an external control for operations and has the connection options listed in [Chapter 3 "Installation"](#).

#### Phase C to Phase A (core 1 – 3)

The rotating field required to operate the motor is applied to phases C to A.

Voltage range: 0 V AC to  $U_{\max}$ .

The following limits must be adhered to for  $U_{\max}$ :

- Note and observe limit speed according to product data sheet.
- $U_{\max} < 50$  V AC (below the Low Voltage Directive).

#### GND<sub>Enc</sub> (core 4)

Ground connection for the absolute encoder.

#### U<sub>DD Enc</sub> (core 5)

Supply voltage for the absolute encoder.

Voltage range: 4.5 ... 5.5 V DC.

#### CLK (core 6)

Input for the clock signal of the serial interface (SSI).

#### Res. (core 7)

Input reserved.

#### DATA (core 8)

Output for the data of the serial interface (SSI).

#### CAUTION!



#### **Malfunction!**

*If a connection cable longer than 30 cm is used between the motor and control, malfunctions can occur during operation.*

- ▶ *The usability of a longer connection cable must be checked for each individual case!*

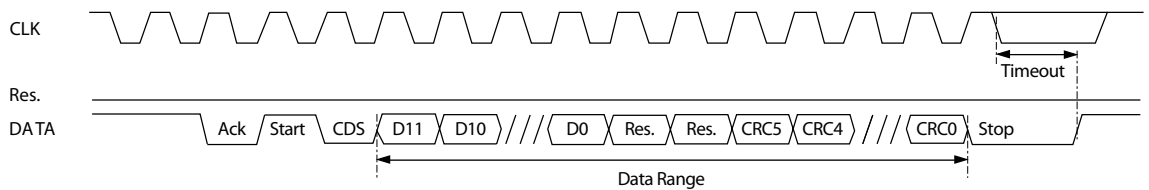


## 4 Functional Description

### 4.3 Motor with AES absolute encoder

#### Synchronous serial interface (SSI)

The synchronous serial interface (SSI) is used to read out the absolute angle positions of the encoder.



After the encoder has sent the acknowledge (Ack), start and control bit (CDS) in the fixed cyclic start sequence, the binary 12 bit sensor data is sent.

Two reserved and six CRC bits then follow.

If no other clock signals are sent to the CLK cable, the encoder runs in a timeout (16  $\mu$ s), which ends the communication. This is also optionally already possible after the 12 bit sensor data.

Angle position values rising in clockwise direction.

Clockwise rotation: Rotation of the output shaft in clockwise direction, viewed from the end of the shaft on the output side of the motor.

## 4 Functional Description

---

### 4.4 Motor with SC speed controller

#### 4.4.1 Connection functions

The servomotor with integrated SC speed controller supports the following functions and/or operating modes:

- Control of the speed through the voltage at the set value input.
- Control of the speed through the coil voltage.
- Control of the direction of rotation at the switch input.
- Reading out the speed signal at the frequency output.

#### **U<sub>P</sub>** (core 1)

Supply voltage for the electronics.

Voltage range: 5 ... 28 V DC.

#### **U<sub>mot</sub>** (core 2)

Supply voltage for the motor winding.

Voltage range: 6 ... 28 V DC.

#### **GND** (core 3)

Common earth.

#### **U<sub>nsoll</sub>** (core 4)

Control voltage for the target velocity.

Voltage range: 0 ... 10 V DC (no speed setpoint is defined for > 10 V DC ... max. U<sub>P</sub>).

If U<sub>nsoll</sub> > 10 V DC, the speed is regulated to the value corresponding to 10 V DC. This value is above the nominal speed so that full control occurs. If U<sub>mot</sub> is increased so that the actual motor speed reaches this target value, it is limited by the speed control to the value corresponding to U<sub>nsoll</sub> = 10 V DC.

The input impedance of this cable is ≥ 5 kΩ.

#### **DIR** (core 5)

Switch input for the motor's direction of rotation.

To earth or U < 0.5 V anti-clockwise, U > 3 V = clockwise.

Maximum allowable level = U<sub>Pmax</sub>.

The input impedance of this cable is ≥ 10 kΩ.

## 4 Functional Description

### 4.4 Motor with SC speed controller

#### FG (core 6)

##### Digital output.

The digital output is a switch which switches to GND (open collector with integrated pull-up resistance of 22 kΩ).

Output voltage: max.  $U_P$ .

Output current: max. 15 mA.

The digital output can be configured for different tasks:

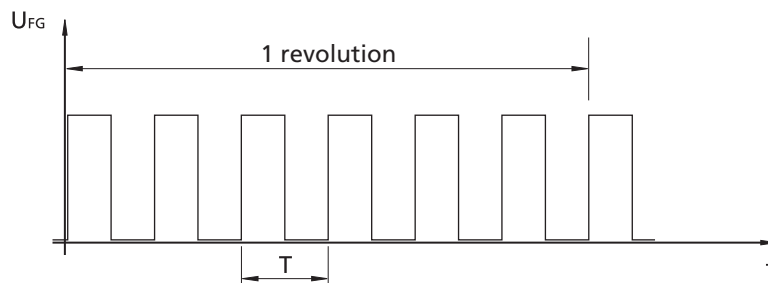
##### Error output

- Output switches to high level if current limiting is activated. The delay between activation of current limiting and activation of the output can be adjusted.
- Output switches to low level if current limiting is deactivated.

##### Frequency output

Frequency output for reading out the actual motor speed.

Signal setup: 6 pulses per motor revolution.

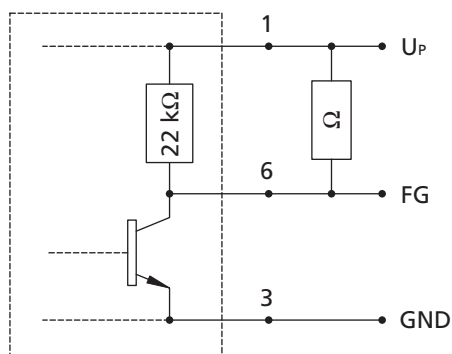


#### NOTE



#### Pull-up resistance

An additional, external pull-up resistance can be connected to increase the edge steepness. The maximum loadability of the digital output must be noted and observed. See circuit diagram:



Due to the coupling of the internal pull-up resistance between FG and the supply voltage  $U_P$ , conducted electromagnetic RF interference, which affects the supply voltage, can drastically worsen the frequency signal.

If operated properly and as intended, the speed and direct of rotation of the motor are not impaired by this interference.

## 4 Functional Description

### 4.4 Motor with SC speed controller

#### PWM operation

If  $U_{\text{nsoll}}$  is specified as the voltage at the motor it is operated with speed control. The speed is controlled by pulse width modulation (PWM), i.e. the motor tries to achieve a constant speed under fluctuating load.

Due to the technical requirements of the motor with SC speed controller, assuming the allowable maximum housing temperature is adhered to, the maximum possible continuous torque in PWM mode may be lower than under full control. The maximum thermally allowable continuous current reduces accordingly.

#### 4.4.2 Configuration

The control parameters of the speed controller integrated in the motor can be individually adjusted to the respective application via a PC. This requires a programming adapter which can be ordered separately as well as a version of the FAULHABER Motion Manager PC software suitable for the speed controller.

The software is available on request or from the FAULHABER homepage <http://www.faulhaber.com/MotionManager>.

#### CAUTION!



#### Risk of damage

*Before starting up, check the parameters configured in the control and if necessary adjust to the connected motor. Incorrectly set values can cause fatal damage to the motor and/or the speed controller. In particular, the following parameters must be correctly set:*

- Duration and maximum current value,
- Generator voltage constant  $k_E$  and connected resistance  $R$ ,
- Controller parameter.

The standard servomotor variant is equipped with digital Hall sensors, with which the commutation signals are determined. The actual speed value is determined via the time interval between the edges of the Hall sensor signals. The motor with Speed Controller SC is also optionally available with analog Hall sensors. In this version speeds from approx. 50 rpm can be stably controlled.

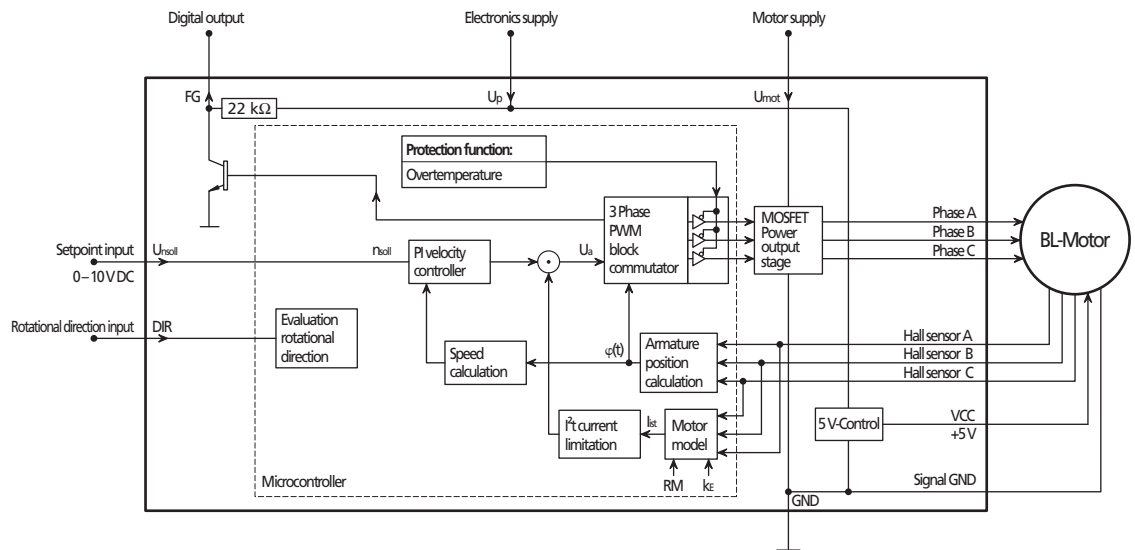
#### Preset default basic parameters:

- Due to the resolution of the digital Hall sensors, speeds from approx. 400 rpm (analog approx. 50 rpm) can be stably controlled.
- PWM frequency at the power output stage: approx. 96 kHz.
- 2-quadrant operation with function for quick speed reduction: The motor windings are short-circuited for faster transition from higher to lower speeds.

## 4 Functional Description

### 4.4 Motor with SC speed controller

#### Block diagram



#### Setting options

- Configuration of the digital output as error output.
- Frequency output can be configured to 6 or 2 pulses per revolution.
- Target velocity value via PWM signal at the target velocity input. See [Chapter 4.4.3 "Special configurations"](#).
- Operation with fixed speed (fixed speed mode). See [Chapter 4.4.3 "Special configurations"](#).
- Operation as voltage controller (volt mode). See [Chapter 4.4.3 "Special configurations"](#).

#### Additional setting options with digital Hall sensors:

- Pure 2-Quadrant operation without active braking option.  
If problems occur during operation with the braking function in the default setting it can be deactivated.
- Filtering (averaging) of the Hall sensor signals.  
If problems occur with the default setting the time of a complete electrical (half) motor revolution is evaluated to obtain a continuous speed signal. This can cause instable motor running at low speeds as the control dynamics worsen.

#### Additional setting options with analog Hall sensors:

The analog Hall sensors supply a continuous speed signal. For this reason, with this optional feature lower speeds up to 50 rpm can be stably controlled.

- 4 quadrant operation with active braking option.

## 4 Functional Description

### 4.4 Motor with SC speed controller

#### 4.4.3 Special configurations

Further setting options exist in addition to the configurations described in [Chapter 4.4.2](#).

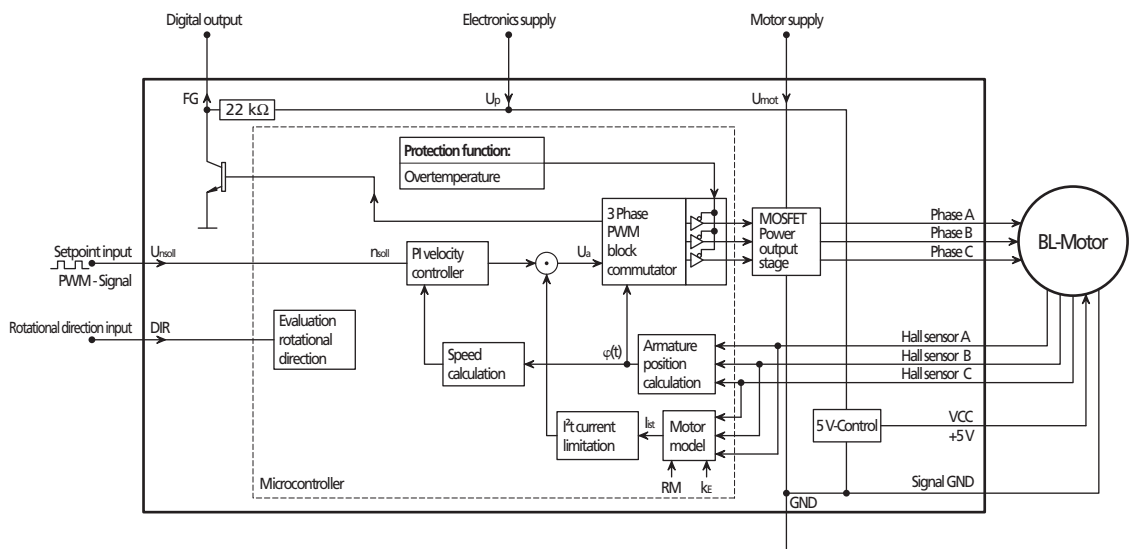
#### Presetting of target velocity value via PWM signal

The target velocity value can be input via a PWM signal if the target velocity input  $U_{n\text{set}}$  is appropriately configured. The target velocity value is proportional to the pulse duty factor.

#### Basic parameter for the pulse duty factor

- PWM frequency range: 500 Hz – 18 kHz.
- Motor stops at pulse duty factor < 2.0 %.
- Motor runs at pulse duty factor > 3.0 %.
- The target velocity is proportional to the pulse duty factor. The maximum target velocity at 100 % can be configured. See [Chapter 4.4.4 "Parameter settings"](#).

Example block diagram (BL motor with Hall sensors):



#### Setting options

- The TTL and PLC levels can be configured as switching levels:

Mode	high level	low level
TTL	> 3.0 V DC	< 0.5 V DC
PLC	> 7.5 V DC	< 2.0 V DC

## 4 Functional Description

---

### 4.4 Motor with SC speed controller

#### Operation with fixed speed (fixed speed mode)

Fixed speed mode is possible for applications in which the servomotor is to be operated with a specific speed only. The target speed to be set is fixed via a parameter. See [Chapter 4.4.4 "Parameter settings"](#).

#### Setting options for nominal speed value input $U_{\text{nsoll}}$

- Quick stop input (low level)
  - Motor stops at  $U_{\text{nsoll}} > 0.15 \text{ V}$ .
  - Motor stops if connection is open.
  - Motor runs at  $U_{\text{nsoll}} > 0.3 \text{ V}$ .
- Quick stop input inverted (high level)
  - Motor runs at  $U_{\text{nsoll}} < 2.0 \text{ V}$ .
  - Motor runs if connection is open.
  - Motor stops at  $U_{\text{nsoll}} > 2.4 \text{ V}$ .
- No function
  - The motor always runs

#### Operation as voltage controller (volt mode)

The integrated speed controller can be configured for function as a voltage controller. The motor voltage is then output proportionally to the voltage at the nominal speed value input  $U_{\text{nsoll}}$ . The current limitation remains active.

With this configuration it is possible to use a master controller. The speed controller is then only used as a power amplifier and for commutation only.

#### Digital output (FG)

The digital output is a switch which switches to GND (open collector with integrated pull-up resistance of  $22 \text{ k}\Omega$ ). It can be configured for different tasks:

- Error output
- Frequency output

The detailed properties of the configurations are described in [Chapter 4.4.1 "Connection functions"](#).

## 4 Functional Description

### 4.4 Motor with SC speed controller

#### 4.4.4 Parameter settings

The following parameters can be used to adjust the integrated speed controller to the respective application.

Several parameters have a function in certain configurations only or with specific settings only.

#### Current limiting values

For the I<sup>2</sup>t current limiting, the peak current ( $I_{max}$ ) and the motor continuous current ( $I_{cont}$ ) must be input. See also [Chapter 4.4.5 "Technical information"](#). The allowable values of the speed controller used as well as of the connected motor must be noted and observed.

Parameter	Meaning	max. value	Units
Peak current ( $I_{max}$ )	Value for the maximum current allowed for a short time (transient maximum current).	3 000*	mA
Motor continuous current ( $I_{cont}$ )	Value for the continuous current which is the limit value.	3 000*	mA

\* Values depend on motor type.

The values can be adjusted if necessary. Note the maximum allowable value for the motor!

#### Fixed speed value

For operation with a fixed speed the nominal speed value is input via an adjustable parameter. See [Chapter 4.4.3 "Special configurations"](#).

Parameter	Meaning	max. value	Units
Fixed speed value ( $N_{setFix}$ )	Nominal speed value, which is input in operation with fixed speed.	65 535	rpm

#### Pulses per motor revolution

It is possible to configure the digital output FG as a frequency output (this is the default configuration).

Parameter	Meaning	Possible values	Units
Pulses per revolution	Number of pulses per revolution at the digital output.	2, 6	1/rev

#### Maximum speed value

When inputting the nominal speed value (as an analog voltage or as a PWM signal) the speed value, which is input at 10 V DC or at 100% pulse duty factor, can be set. The maximum speed value can therefore be adjusted to the application.

Different resolutions of the maximum speed value and different maximum values are possible, depending on the operating mode and motor type.

Parameter	Meaning	max. value	Units
Maximum speed value ( $N_{setMax}$ )	Maximum nominal speed value at 10 V or 100 % pulse duty factor at the nominal speed value input $U_{hsoll}$ .	60 000	rpm



## 4 Functional Description

### 4.4 Motor with SC speed controller

#### Controller parameters

The integrated speed controller is set in the factory so that problem free operation is usually possible. The speed controller has an integrated feature for specifying appropriate parameters if adjustment of the governor to the controlled system is necessary for special applications. See [Chapter 4.4.5 "Technical information"](#).

The targets set for the control's properties also depend on the application.

Above all, a differentiation is made between the stiffness of the control, the uniformity of the speed within a revolution, the allowed system deviation, the allowed overshoot and the required stability reserves.

The control circuit must also satisfy these requirements so that the controller parameters must also be adjusted with respect to these.

The PI speed controller used here enables two parameters to be set (proportional and integral-action component).

Parameter	Meaning	max. value	Units
V	Proportional component	32 767	Digit
VI	Proportional component multiplied by the integral-action component	65 535	Digit

#### Delayed Current Error (with error output only)

Activation of the output can be delayed. Even if the current is already limited the output is not activated until after the time input with DCE. As a result, short-term exceeding of the limit current can be ignored.

Parameter	Meaning	max. value	Units
Delayed Current Error (DCE)	Delay of activation of the error output	5 100	ms

## 4 Functional Description

### 4.4 Motor with SC speed controller

#### 4.4.5 Technical information

##### $I^2t$ current limiting

The servomotor with integrated SC speed controller is equipped with current limiting which enables certain motor protection to be achieved.

- Peak current ( $I_{max}$ )

The current is limited to the peak current, provided that the thermal current model calculates a non-critical temperature.

- Continuous current ( $I_{cont}$ )

If the thermal current model reaches a critical temperature, continuous current is switched to.

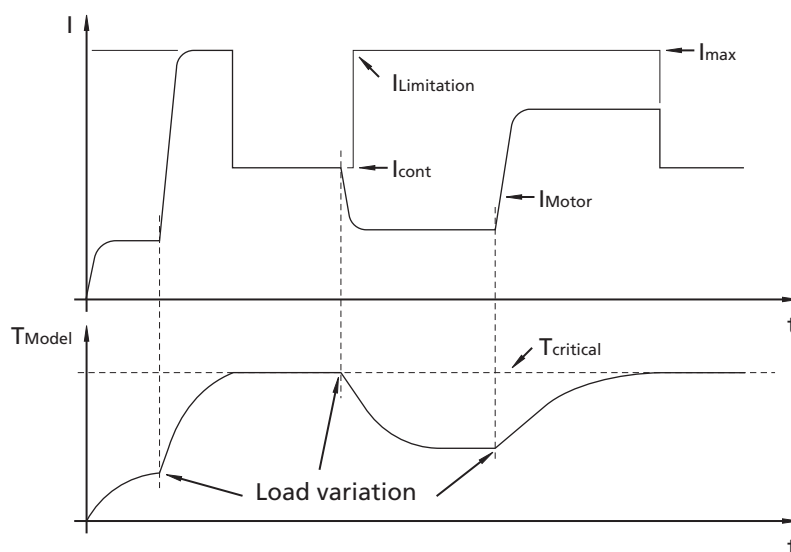
##### How the current limiting works:

When the motor starts, the peak current is preset as the set-point for the current controller. As the load increases, the current in the motor constantly increases until it finally reaches the peak current. The current controller then comes into operation and limits the current to this set-point.

A thermal current model operating in parallel calculates a model temperature from the actually flowing current. If this model temperature exceeds a critical value, continuous current is switched to and the motor current is regulated to this. Only when the load becomes so small that the temperature falls below the critical model temperature is peak current permitted again.

The following diagram symbolically shows how the current limiting functions by means of an envelope curve ( $I_{limiting}$ ). The current may not rise above the values along this envelope curve.

The aim of this so-called  $I^2t$  current limiting is not to heat the motor above the thermally allowable temperature by selecting a suitable continuous current. On the other hand, a high load should be temporarily possible in order to enable very dynamic movements.



## 4 Functional Description

### 4.4 Motor with SC speed controller

#### Overtemperature cut-off

The motor is deactivated if the temperature of the electronics exceeds the limit value of 100 °C.

The following condition must be fulfilled to reactivate the motor:

- Temperature below the preset limit value.

#### Adjustment of the controller parameters

The controller parameters are already preset for common applications. However, the controller parameters can be optimised to optimally adjust the controller to the respective application.

The digital controller operates with a sampling rate of approx. 500 µs.

#### Example of controller setting:

1. Set the initial configuration.
2. Increase controller gain (proportional component V).
3. Input speed jump from 1/3 of the maximum speed to 2/3.
4. Speed jump from 2/3 to 1/3 and observe behaviour.
5. Repeat steps 2 to 4, until the controller becomes unstable. Then reduce controller amplification until stability is reliably ensured.
6. Repeat steps 2 to 5 with proportional integral-action component (VI).

#### Effect of pulse width modulation (PWM)

The power output stage of the integrated speed controller operates with so-called pulse width modulation (PWM). At a fixed frequency (the PWM frequency) the pulse duty factor is set between the on time and the off time depending on the controller output value.

The advantage of this procedure is that the losses in the drive electronics are very low. In contrast, the losses in a linear output stage can be very large and it becomes hot.

When the PWM is used the motor's inductance is used as a filter for the current. Therefore, the PWM frequency should be high enough to adequately filter the current.

#### NOTE



#### Pulse duty factor

*The PWM frequency of the speed controller is optimally matched to the connected motor. Nevertheless, it must be noted that with a low PWM pulse duty factor and larger motor load caused by short-term high current flow in the motor, substantially higher losses can occur than with a large pulse duty factor.*

- ▶ *As large a pulse duty factor as possible should set in at the operating point. The required control reserve must also be noted and observed!*
- ▶ *To achieve this, if necessary, the motor operating voltage can be reduced.*

#### NOTE



#### Efficiency

*Please note that a reduction in efficiency at the motor also reduces the maximum allowable current and therefore the maximum continuous torque.*

## 5 Operation

### 5.1 Commissioning

Before starting up the servomotor together with a mechanism, the following points must be checked:

- The motor has been installed according to the specifications.
- The ribbon cable of the motor is connected according to the requirements (risk of polarity reversal!) and is laid so that it cannot be damaged during operation. The maximum load values must be noted and observed. See [Chapter 1.4 "Ambient conditions"](#).
- Lengthening the connection leads can affect the function and properties with respect to EMC. All connection leads may not exceed a length of 3 m.
- The connected mechanism is installed free of blockages.
- The loads and stresses on the shaft (axial, radial and torques) are within the specified values.

#### **CAUTION!**



#### **Risk of injuries**

*A risk of injuries can result from protruding rotating or moving parts of the driven mechanism.*

- ▶ *Cover rotating and moving parts with appropriate devices.*

#### **CAUTION!**



#### **Risk of burns**

*Depending on the load and ambient temperature, very high temperatures can occur on the surface of the unit.*

- ▶ *Contact protection (guards) must be provided if necessary.*

## 6 EC Product Safety Directives

---

**REGULATION!** The following EC Product Safety Directives are important for users of the described products:



**Machinery Directive (2006/42/EC):**

Due to their small size, small standard electrical drives cannot cause any noteworthy risk of injuries to people.

Therefore, the Machinery Directive does not apply to our products.

The products described here are not “part machines” or “incomplete machines”.

Therefore, Faulhaber does not provide a standard Declaration of Incorporation.

**Low-Voltage Directive (2006/95/EC):**

It applies to all electrical equipment with a nominal voltage from 75 to 1 500 V DC, or from 50 to 1 000 V AC. The products described in this technical manual do not fall within the scope of this Directive as they are designed for smaller voltages.

**EMC Directive (2014/30/EU):**

The Electromagnetic Compatibility (EMC) Directive applies to all electronic and electrical equipment, plant and systems sold to end users (consumers). In addition, CE marking can be undertaken for built-in components according to the EMC Directive. Compliance is documented by the Declaration of Conformity.

## 7 Warranty

---

### Note

Dr. Fritz Faulhaber GmbH & Co. KG products are produced to state of the art production methods and are subject to strict quality control.

All sales and deliveries made exclusively on the basis of our general Terms and Conditions of Business. These are available to view and download on the FAULHABER homepage at [www.faulhaber.com/agb](http://www.faulhaber.com/agb).

## Notes

---

