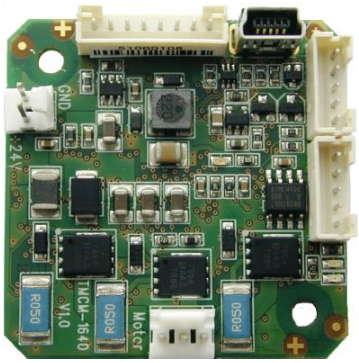
Firmware Version V2.10

TMCL™ FIRMWARE MANUAL



TMCM-1640

1-Axis BLDC
Controller / Driver Module
5A / 24V
Hall Sensor Interface
Encoder Interface
RS485 and USB Interface
FOC Firmware

TRINAMIC Motion Control GmbH & Co. KG
Hamburg, Germany

www.trinamic.com

TRINAMIC
MOTION CONTROL

Table of Contents

1 Features

The TMCM-1640 is a highly compact controller/driver module for brushless DC (BLDC) motors with up to 5A coil current, optional encoder and/or hall sensor feedback. For communication the module offers RS485 and (mini-)USB interface.

Applications

- Compact single-axis brushless DC motor solutions

Electrical data

- Supply voltage: +24V DC nom. (+14,5V… +28.5V DC)
- Motor current: up to 5A RMS (programmable)

Integrated motion controller

- High performance microcontroller for system control and communication protocol handling

Integrated driver

- High performance integrated pre-driver (TMC603)
- High-efficient operation, low power dissipation (MOSFETs with low $R_{DS(ON)}$)
- Dynamic current control
- Integrated protection

Interfaces

- USB (mini-USB, full speed (12Mbit/s)) serial communication interface
- RS485 serial communication interface
- Hall sensor interface (+5V TTL or open-collector signals)
- Encoder interface (+5V TTL or open-collector signals)
- General purpose inputs (2x digital (+5V / +24V compatible), 1x analogue (+0… +10V)
- 1 general purpose output (open-drain)

Software

- Available with TMCL
- Standalone operation or remote controlled operation
- Program memory (nonvolatile) for up to 2048 TMCL commands
- PC-based application development software TMCL-IDE

Refer to separate TMCM-1640 Hardware Manual, too.

2 Overview

The software running on the microprocessor of the TMCM-1640 consists of two parts, a boot loader and the firmware itself. Whereas the boot loader is installed during production and testing at TRINAMIC and remains – normally – untouched throughout the whole lifetime, the firmware can be updated by the user. New versions can be downloaded free of charge from the TRINAMIC website (http://www.trinamic.com).

The firmware is related to the standard TMCL firmware with regard to protocol and commands. The module is based on the ARM Cortex-M3 microcontroller and the high performance pre-driver TMC603 and supports the standard TMCL with a special range of values.

The new FOC firmware V2.0 is field oriented control software for brushless DC applications. It is developed for high-performance motor applications which can operate smoothly over the full velocity range, can generate full torque at zero speed and is capable of fast acceleration and deceleration. This saves energy and quiets rotating machinery.

3 Putting the TMCM-1640 into Operation

Here you can find basic information for putting your module into operation. The text contains a simple example for a TMCL program and a short description of operating the module in direct mode.

THINGS YOU NEED:

- TMCM-1640
- USB interface and appropriate cable or RS485 interface / adapter and appropriate cable
- Nominal supply voltage +24V DC (+14,5… +28.5V DC) for your module with sufficient output filtering (to be sure add e.g. 2200µF capacitor close to power supply input of module)
- BLDC motor, e.g. one of TRINAMICs QBL4208 motors
- Encoder optional
- TMCL-IDE program and PC

PRECAUTIONS

- Do not mix up connections or short-circuit pins.
- Avoid bounding I/O wires with motor power wires as this may cause noise picked up from the motor supply.
- The power supply has to be buffered by a capacitor. Otherwise the module will be damaged!
- Do not exceed the maximum power supply of 28.5V DC.
- Do not connect or disconnect the motor while powered!
- Start with power supply OFF!

3.1 Starting up

The following figure shows how the connectors have to be used.

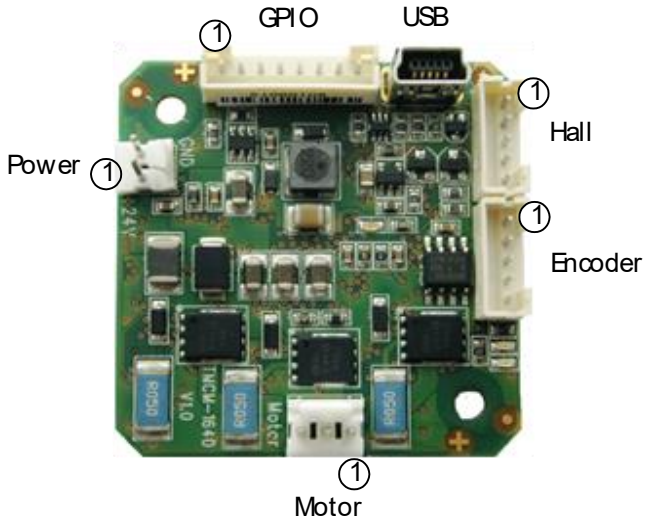


Figure 3.1 Connectors

Domain	Connector type	Mating connector type
Power	Tyco electronics (formerly AMP) MTA-100 series (3-640456-2), 2 pol., male	MTA 100 series (3-640441-2), 2 pol., female
Motor	Tyco electronics (formerly AMP) MTA-100 series (3-640456-3), 3 pol., male	MTA 100 series (3-640441-3), 3 pol., female
USB	5-pin standard mini-USB connector, female	5-pin standard mini-USB connector, male
Hall	2mm pitch 5 pin JST B5B-PH-K connector	Housing: JST PHR-5 Crimp contacts: BPH-002T-P0.5S (0.5-0.22mm)
Encoder	2mm pitch 5 pin JST B5B-PH-K connector	Housing: JST PHR-5 Crimp contacts: BPH-002T-P0.5S (0.5-0.22mm)
I/O, RS485	2mm pitch 8 pin JST B8B-PH-K connector	Housing: JST PHR-8 Crimp contacts: BPH-002T-P0.5S (0.5-0.22mm)

1. Connect the motor:

Pin	Label	Description
1	BM1	Motor coil phase 1 / U
2	BM2	Motor coil phase 2 / V
3	BM3	Motor coil phase 3 / W

2. Connect the encoder (optional):

Pin	Label	Description
1	GND	Encoder supply and signal ground
2	+5V	+5V output for encoder supply (max. 100mA)
3	A	Encoder channel a
4	B	Encoder channel b
5	N	Encoder index / null channel

3. Connect the hall sensor:

Pin	Label	Description
1	GND	Encoder supply and signal ground
2	+5V	+5V output for hall sensor supply
3	HALL_1	Hall sensor signal 1
4	HALL_2	Hall sensor signal 2
5	HALL_3	Hall sensor signal 3

4. Connect the I/Os and the RS485 interface, if needed:

Pin	Label	Description
1	GND	Signal and system ground
2	+5V	+5V output for supply of external circuit (max. 100mA)
3	AIN	Analog input (0..10V), may be used as velocity control input in standalone mode (depending on initial script)
4	IN_0	Digital input, may be used as stop (STOP_R) / limit switch input (if activated)
5	IN_1	Digital input, may be used as stop (STOP_L) / limit switch input (if activated)
6	OUT	Digital output (open-drain, max. 100mA)
7	RS485+	RS485 2-wire serial interface (non-inverted signal)
8	RS485-	RS485 2-wire serial interface (inverted signal)

5. Connect the USB interface:

Pin	Label	Description
1	VBUS	+5V power
2	D-	Data –
3	D+	Data +
4	ID	Not connected
5	GND	Ground

6. Connect the power supply as follows:

Pin	Label	Description
1	+U	Module and driver stage power supply input
2	GND	Module ground (power supply and signal ground)

Please note, that there is no protection against reverse polarity and only limited protection against voltages above the upper maximum limit. The power supply typically should be within a range of +14,5 to +28.5V.

When using supply voltages near the upper limit, a regulated power supply is mandatory. Please ensure that enough power filtering capacitors are available in the system (2200µF or more recommended) in order to absorb energy fed back by the motor while the motor is decelerating and in order to prevent any voltage surge e.g. during power-on (especially with longer power supply cables as there are only ceramic filter capacitors on-board). In larger systems an additional external zener/suppressor diode with adequate voltage rating might be necessary in order to limit the maximum voltage.

To ensure reliable operation of the unit, the power supply has to have a sufficient output capacitor and the supply cables should have a low resistance, so that the chopper operation does not lead to an increased power supply ripple directly at the unit. Power supply ripple due to the chopper operation should be kept at a maximum of a few 100mV

GUIDELINES FOR POWER SUPPLY:
a) keep power supply cables as short as possible
b) use cables with large diameters for power supply cables
c) add 2200µF or larger filter capacitors near the motor driver unit especially if the distance to the power supply is large (i.e. more than 2-3m)

7. Switch ON the power supply
The power LED glows now. If this does not occur, switch power OFF and check your connections as well as the power supply.

8. Start the TMCL-IDE software development environment
The TMCL-IDE is available on www.trinamic.com.

4 TMCL

The TMCM-1640 module supports TMCL direct mode and standalone TMCL program execution. You can store up to 2048 TMCL instructions on it.

In direct mode the TMCL communication over USB/RS485 follows a strict master/slave relationship. That is, a host computer (e.g. PC/PLC) acting as the interface bus master will send a command to the module. The TMCL interpreter on it will then interpret this command, do the initialization of the motion controller, read inputs and write outputs or whatever is necessary according to the specified command. As soon as this step has been done, the module will send a reply back over USB/RS485 to the bus master. The master should not transfer the next command till then. Normally, the module will just switch to transmission and occupy the bus for a reply, otherwise it will stay in receive mode. It will not send any data over the interface without receiving a command first. This way, any collision on the bus will be avoided when there are more than two nodes connected to a single bus.

The Trinamic Motion Control Language (TMCL) provides a set of structured motion control commands. Every motion control command can be given by a host computer or can be stored on the TMCM-1640 to form programs that run standalone on the module.

Every command has a binary representation and a mnemonic:

- The binary format is used to send commands from the host to a module in direct mode.
- The mnemonic format is used for easy usage of the commands when developing standalone TMCL applications with the TMCL-IDE (IDE means *Integrated Development Environment*).

There is also a set of configuration variables for the axis and for global parameters which allow individual configuration of nearly every function of a module. This manual gives a detailed description of all TMCL commands and their usage.

4.1 Binary Command Format

When commands are sent from a host to a module, the binary format has to be used. Every command consists of a one-byte command field, a one-byte type field, a one-byte motor/bank field and a four-byte value field. So the binary representation of a command always has seven bytes.

When a command is to be sent via USB interface, it has to be enclosed by an address byte at the beginning and a checksum byte at the end. In this case it consists of nine bytes.

The binary command format for USB and RS485 is structured as follows:

Bytes	Meaning
1	Module address
1	Command number
1	Type number
1	Motor or Bank number
4	Value (MSB first!)
1	Checksum

Checksum calculation
As mentioned above, the checksum is calculated by adding up all bytes (including the module address byte) using 8-bit addition. Here is an example for the calculation:

in C:
```
unsigned char i, Checksum;
unsigned char Command[9];

//Set the "Command" array to the desired command
Checksum = Command[0];
for(i=1; i<8; i++)
      Checksum+=Command[i];

Command[8]=Checksum; //insert checksum as last byte of the command
//Now, send the command back to the module
```

4.2 Reply Format

Every time a command has been sent to a module, the module sends a reply.

The reply format for USB and RS485 is structured as follows:

Bytes	Meaning
1	Reply address
1	Module address
1	Status (e.g. 100 means *no error*)
1	Command number
4	Value (MSB first!)
1	Checksum

- The checksum is also calculated by adding up all the other bytes using an 8-bit addition.
- Do not send the next command before you have received the reply!

4.2.1 Status Codes

The reply contains a status code.

The status code can have one of the following values:

Code	Meaning
100	Successfully executed, no error
101	Command loaded into TMCL program EEPROM
1	Wrong checksum
2	Invalid command
3	Wrong type
4	Invalid value
5	Configuration EEPROM locked
6	Command not available

4.3 Standalone Applications

The module is equipped with an EEPROM for storing TMCL applications. You can use the TMCL-IDE for developing standalone TMCL applications. You can load your program down into the EEPROM and then it will run on the module. The TMCL-IDE contains an *editor* and a TMCL *assembler* where the commands can be entered using their mnemonic format. They will be assembled automatically into their binary representations. Afterwards this code can be downloaded into the module to be executed there.

4.4 TMCL Command Overview

The following section provides a short overview of the TMCL commands supported by the TMCM-1640.

4.4.1 Motion Commands

These commands control the motion of the motor. They are the most important commands and can be used in direct or in standalone mode.

Mnemonic	Command number	Meaning
ROL	2	Rotate left
ROR	1	Rotate right
MVP	4	Move to position
MST	3	Motor stop

4.4.2 Parameter Commands

These commands are used to set, read and store axis parameters or global parameters. Axis parameters can be set independently for the axis, whereas global parameters control the behavior of the module itself. These commands can also be used in direct mode and in standalone mode.

Mnemonic	Command number	Meaning
SAP	5	Set axis parameter
GAP	6	Get axis parameter
STAP	7	Store axis parameter into EEPROM
RSAP	8	Restore axis parameter from EEPROM
SGP	9	Set global parameter
GGP	10	Get global parameter
STGP	11	Store global parameter into EEPROM
RSGP	12	Restore global parameter from EEPROM

4.4.3 Control Commands

These commands are used to control the program flow (loops, conditions, jumps etc.) in standalone mode, only.

Mnemonic	Command number	Meaning
JA	22	Jump always
JC	21	Jump conditional
COMP	20	Compare accumulator with constant value
CSUB	23	Call subroutine
RSUB	24	Return from subroutine
WAIT	27	Wait for a specified event
STOP	28	End of a TMCL program

4.4.4 I/O Port Commands

These commands control the external I/O ports and can be used in direct mode and in standalone mode.

Mnemonic	Command number	Meaning
SIO	14	Set output
GIO	15	Get input

4.4.5 Calculation Commands

These commands are intended to be used for calculations within TMCL applications in standalone mode, only. For calculating purposes there are an accumulator (or accu or A register) and an X register. When executed in a TMCL program (in standalone mode), all TMCL commands that read a value store the result in the accumulator. The X register can be used as an additional memory when doing calculations. It can be loaded from the accumulator.

Mnemonic	Command number	Meaning
CALC	19	Calculate using the accumulator and a constant value
CALCX	33	Calculate using the accumulator and the X register
AAP	34	Copy accumulator to an axis parameter
AGP	35	Copy accumulator to a global parameter

MIXING STANDALONE PROGRAM EXECUTION AND DIRECT MODE

It is possible to use some commands in direct mode while a standalone program is active. When a command which reads out a value is executed (direct mode) the accumulator will not be affected. While a TMCL program is running standalone on the module, a host can still send commands like GAP and GGP to it (e.g. to query the actual position of the motor) without affecting the flow of the TMCL program running standalone on the module.

4.5 Commands

The module specific commands are explained in more detail on the following pages. They are listed according to their command number.

4.5.1 ROR (rotate right)

The motor will be instructed to rotate with a specified velocity in *right* direction (increasing the position counter).

Internal function: First, velocity mode is selected. Then, the velocity value is transferred to axis parameter #2 (*target velocity*).

Related commands: ROL, MST, SAP, GAP

Mnemonic: ROR 0, <velocity>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE <velocity>
1	don't care	0	-200000… +200000

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	1	don't care

Example:
Rotate right, velocity = 350
Mnemonic: ROR 0, 350

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$01	$00	$00	$00	$00	$01	$5e

4.5.2 ROL (rotate left)

The motor will be instructed to rotate with a specified velocity (opposite direction compared to ROR, decreasing the position counter).

Internal function: First, velocity mode is selected. Then, the velocity value is transferred to axis parameter #2 (*target velocity*).

Related commands: ROR, MST, SAP, GAP

Mnemonic: ROL 0, <velocity>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE <velocity>
2	don't care	0	-200000… +200000

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	2	don't care

Example:

Rotate left, velocity = 1200
Mnemonic: ROL 0, 1200

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$02	$00	$00	$00	$00	$04	$b0

4.5.3 MST (motor stop)

The motor will be instructed to stop.

Internal function: The axis parameter *target velocity* is set to zero.

Related commands: ROL, ROR, SAP, GAP

Mnemonic: MST 0

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
3	don't care	0	don't care

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	3	don't care

Example:

Stop motor
Mnemonic: MST 0

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$03	$00	$00	$00	$00	$00	$00

4.5.4 MVP (move to position)

The motor will be instructed to move to a specified relative or absolute position. It uses the acceleration/deceleration ramp and the positioning speed programmed into the unit. This command is non-blocking (like all commands). A reply will be sent immediately after command interpretation. Further commands may follow without waiting for the motor reaching its end position. The maximum velocity and acceleration are defined by axis parameters #4 and #11.

TWO OPERATION TYPES ARE AVAILABLE:

- Moving to an absolute position in the range from -2147483648… +2147483647.
- Starting a relative movement by means of an offset to the actual position. In this case, the new resulting position value must not exceed the above mentioned limits, too.

Internal function: A new position value is transferred to the axis parameter #0 *target position*.

Related commands: SAP, GAP, and MST

Mnemonic: MVP <ABS|REL>, 0, <position|offset value>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
4	0 ABS – absolute	0	<position> -2147483648… +2147483647
	1 REL – relative	0	<offset> -2147483648… +2147483647

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	4	don't care

Example MVP ABS:

Move motor to (absolute) position 9000
Mnemonic: MVP ABS, 0, 9000

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$04	$00	$00	$00	$00	$23	$28

Example MVP REL:

Move motor from current position 1000 steps backward (move relative -1000)
Mnemonic: MVP REL, 0, -1000

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$00	$04	$01	$00	$ff	$ff	$fc	$18

4.5.5 SAP (set axis parameter)

Most of the motion control parameters of the module can be specified by using the SAP command. The settings will be stored in SRAM and therefore are volatile. Thus, information will be lost after power off. ***Please use command STAP (store axis parameter) in order to store any setting permanently.***

Related commands: GAP, STAP, and RSAP

Mnemonic: SAP <parameter number>, 0, <value>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
5	<parameter number>	0	<value>

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	5	don't care

A list of all parameters which can be used for the SAP command is shown in section 5.

Example:

Set the absolute maximum current to 2000mA
Mnemonic: SAP 6, 0, 2000

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$05	$06	$00	$00	$00	$07	$D0

4.5.6 GAP (get axis parameter)

Most parameters of the TMCM-1640 can be adjusted individually. They can be read out using the GAP command.

Related commands: SAP, STAP, and RSAP

Mnemonic: GAP <parameter number>, 0

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
6	<parameter number>	0	don't care

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	6	don't care

A list of all parameters which can be used for the GAP command is shown in section 5.

Example:

Get the actual motor position
Mnemonic: GAP 1, 0

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$06	$01	$00	$00	$00	$00	$00

Reply:

Byte Index	0	1	2	3	4	5	6	7
Function	Host-address	Target-address	Status	Instruction	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$00	$01	$64	$06	$00	$00	$02	$c7

4.5.7 STAP (store axis parameter)

The STAP command stores an axis parameter previously set with a *Set Axis Parameter command (SAP)* permanently. Most parameters are automatically restored after power up.

Internal function: An axis parameter value stored in SRAM will be transferred to EEPROM and loaded from EEPORM after next power up.

Related commands: SAP, RSAP, and GAP

Mnemonic: STAP <parameter number>, 0

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
7	<parameter number>	0	don't care*

*** The value operand of this function has no effect. Instead, the currently used value (e.g. selected by SAP) is saved.**

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	7	don't care

A list of all parameters which can be used for the STAP command is shown in section 5.

Example:

Store the maximum speed
Mnemonic: STAP 4, 0

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$07	$04	$00	$00	$00	$00	$00

Note: The STAP command will not have any effect when the configuration EEPROM is locked. The error code 5 (configuration EEPROM locked) will be returned in this case.

4.5.8 RSAP (restore axis parameter)

For all configuration related axis parameters non-volatile memory locations are provided. By default, most parameters are automatically restored after power up. A single parameter that has been changed before can be reset by this instruction also.

Internal function: The specified parameter is copied from the configuration EEPROM memory to its RAM location.

Related commands: SAP, STAP, and GAP

Mnemonic: RSAP <parameter number>, 0

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
8	<parameter number>	0	don't care

Reply in direct mode:

STATUS	COMMAND	VALUE
100 – OK	8	don't care

A list of all parameters which can be used for the RSAP command is shown in section 5.

Example:

Restore the maximum current
Mnemonic: RSAP 6, 0

Binary:

Byte Index	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$08	$06	$00	$00	$00	$00	$00

4.5.9 SGP (set global parameter)

Global parameters are related to the host interface, peripherals or other application specific variables. The different groups of these parameters are organized in *banks* to allow a larger total number for future products. Currently, only bank 0 and 1 are used for global parameters, and only bank 2 is intended to use for user variables.

Related commands: GGP, STGP, RSGP

Mnemonic: SGP <parameter number>, <bank number>, <value>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
9	<parameter number>	<bank number>	<value>

Reply in direct mode:

STATUS	VALUE
100 – OK	don't care

A list of all parameters which can be used for the SGP command is shown in section 6.

Example:

Set variable 0 at bank 2 to 100
Mnemonic: SGP, 0, 2, 100

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$09	$00	$02	$00	$00	$00	$64

4.5.10 GGP (get global parameter)

All global parameters can be read with this function.

Related commands: SGP, STGP, RSGP

Mnemonic: GGP <parameter number>, <bank number>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
10	<parameter number>	<bank number>	don't care

Reply in direct mode:

STATUS	VALUE
100 – OK	<value>

A list of all parameters which can be used for the GGP command is shown in section 6.

Example:

Get variable 0 from bank 2
Mnemonic: GGP, 0, 2

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$0a	$00	$02	$00	$00	$00	$00

4.5.11 STGP (store global parameter)

Some global parameters are located in RAM memory, so modifications are lost at power down. This instruction copies a value from its RAM location to the configuration EEPROM and enables permanent storing. Most parameters are automatically restored after power up.

Related commands: SGP, GGP, RSGP

Mnemonic: STGP <parameter number>, <bank number>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
11	<parameter number>	<bank number>	don't care

Reply in direct mode:

STATUS	VALUE
100 – OK	don't care

A list of all parameters which can be used for the STGP command is shown in section 6.

Example:

Copy variable 0 at bank 2 to the configuration EEPROM
Mnemonic: STGP, 0, 2

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$0b	$00	$02	$00	$00	$00	$00

4.5.12 RSGP (restore global parameter)

This instruction copies a value from the configuration EEPROM to its RAM location and so recovers the permanently stored value of a RAM-located parameter. Most parameters are automatically restored after power up.

Related commands: SGP, GGP, STGP

Mnemonic: RSGP <parameter number>, <bank number>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
12	<parameter number>	<bank number>	don't care

Reply in direct mode:

STATUS	VALUE
100 – OK	don't care

A list of all parameters which can be used for the RSGP command is shown in section 6.

Example:

Copy variable 0 at bank 2 from the configuration EEPROM to the RAM location
Mnemonic: RSGP, 0, 2

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$0c	$00	$02	$00	$00	$00	$00

4.5.13 SIO (set output) and GIO (get input / output)

The TMCM-1640 provides two commands for dealing with inputs and outputs:

- ***SIO*** sets the status of the general digital output either to low (0) or to high (1).
- With ***GIO*** the status of the two available general purpose inputs of the module can be read out. The command reads out a digital or analogue input port. Digital lines will read 0 and 1, while the ADC channel delivers 12 bit in the range of 0… 4095.

CORRELATION BETWEEN I/OS AND BANKS

Inputs/ Outputs	Bank	Description
Digital inputs	Bank 0	Digital inputs are accessed in bank 0.
Analogue inputs	Bank 1	Analog inputs are accessed in bank 1.
Digital outputs	Bank 2	The states of the OUT lines (that have been set by SIO commands) can be read back using bank 2.

4.5.13.1 SIO (set output)

Bank 2 is used for setting the status of the general digital output either to low (0) or to high (1).

Internal function: the passed value is transferred to the specified output line.

Related commands: GIO, WAIT

Mnemonic: SIO <port number>, <bank number>, <value>

Binary representation:

INSTRUCTION NO.	TYPE	MOT/BANK	VALUE
14	<port number>	<bank number> 2	<value> 0/1

Reply structure:

STATUS	VALUE
100 – OK	don't care

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$0e	$07	$02	$00	$00	$00	$01

4.5.13.2 GIO (get input/output)

GIO can be used in direct mode or in standalone mode.

GIO IN STANDALONE MODE

In standalone mode the requested value is copied to the accumulator (accu) for further processing purposes such as conditioned jumps.

GIO IN DIRECT MODE

In direct mode the value is output in the value field of the reply without affecting the accumulator. The actual status of a digital output line can also be read.

Internal function: the specified line is read.

Related commands: SIO, WAIT

Mnemonic: GIO <port number>, <bank number>

Binary representation:

INSTRUCTION NO.	TYPE	MOT/BANK	VALUE
15	<port number>	<bank number>	don't care

Reply in direct mode:

STATUS	VALUE
100 – OK	<status of the port>

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$0f	$00	$01	$00	$00	$00	$00

Reply:

Byte Index	0	1	2	3	4	5	6	7
Function	Host-address	Target-address	Status	Instruction	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$02	$01	$64	$0f	$00	$00	$01	$2e

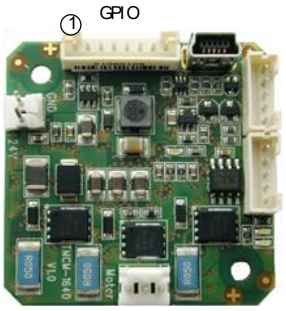


Figure 4.1 GPIO connector of TMCM-1640

PROVIDED SIO AND GIO COMMANDS

Pin	Digital	Analog	GIO <port>, <bank>	SIO <port>, <bank>, <value>	Value range
3	-	x	GIO 0, 1 (ADC_IN_0)	-	0… 4095
-	-	x	GIO 1, 1 (Phase A)	-	0… 4095
-	-	x	GIO 2, 1 (Phase B)	-	0… 4095
-	-	x	GIO 3, 1 (Phase C)	-	0… 4095
-	-	x	GIO 4, 1 (VSupply)	-	0… 4095
-	-	x	GIO 5, 1 (Temp)	-	0… 4095
4	x	-	GIO 0, 0 (IN_0)	-	0/1
5	x	-	GIO 1, 0 (IN_1)	-	0/1
6	x	-	GIO 0, 2 (OUT_0)	SIO 0, 2, <value>	0/1

4.5.14 CALC (calculate)

A value in the accumulator variable, previously read by a function such as GAP (get axis parameter), can be modified with this instruction. Nine different arithmetic functions can be chosen and one constant operand value must be specified. The result is written back to the accumulator, for further processing like comparisons or data transfer.

Related commands: CALCX, COMP, JC, AAP, AGP, GAP, GGP, GIO

Mnemonic: CALC <op>, <value>

Binary representation:

COMMAND	TYPE <op>	MOT/BANK	VALUE
19	0 ADD – add to accu 1 SUB – subtract from accu 2 MUL – multiply accu by 3 DIV – divide accu by 4 MOD – modulo divide by 5 AND – logical and accu with 6 OR – logical or accu with 7 XOR – logical exor accu with 8 NOT – logical invert accu 9 LOAD – load operand to accu	don't care	<operand>

Example:
Multiply accu by -5000
Mnemonic: CALC MUL, -5000

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$13	$02	$00	$FF	$FF	$EC	$78

4.5.15 COMP (compare)

The specified number is compared to the value in the accumulator register. The result of the comparison can be used for example by the conditional jump (JC) instruction. This command is intended for use in standalone operation, only. The host address and the reply are required to take the instruction to the TMCL program memory while the TMCL program downloads. It does not make sense to use this command in direct mode.

Internal function: The specified value is compared to the internal *accumulator*, which holds the value of a preceding *get* or calculate instruction (see GAP/GGP/CALC/CALCX). The internal arithmetic status flags are set according to the comparison result.

Related commands: JC (jump conditional), GAP, GGP, CALC, CALCX

Mnemonic: COMP <value>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
20	don't care	don't care	<comparison value>

Example:

Jump to the address given by the label when the position of the motor #0 is greater or equal to 1000.

```
GAP 1, 0, 0       //get axis parameter, type: no. 1 (actual position), motor: 0, value: 0 don't care
COMP 1000         //compare actual value to 1000
JC GE, Label      //jump, type: 5 greater/equal, the label must be defined somewhere else in the program
```

Binary format of the COMP 1000 command:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$14	$00	$00	$00	$00	$03	$e8

4.5.16 JC (jump conditional)

The JC instruction enables a conditional jump to a fixed address in the TMCL program memory, if the specified condition is met. The conditions refer to the result of a preceding comparison. This function is for standalone operation only. The host address and the reply are required to take the instruction to the TMCL program memory while the TMCL program downloads. It is not possible to use this command in direct mode.

Internal function: The TMCL program counter is set to the passed value if the arithmetic status flags are in the appropriate state(s).

Related commands: JA, COMP, WAIT

Mnemonic: JC <condition>, <label>
where <condition>=ZE|NZ|EQ|NE|GT|GE|LT|LE|ETO|EAL

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
21	0 ZE - zero 1 NZ - not zero 2 EQ - equal 3 NE - not equal 4 GT - greater 5 GE - greater/equal 6 LT - lower 7 LE - lower/equal 8 ETO - time out error 9 EAL - external alarm	don't care	<jump address>

Example:

Jump to address given by the label when the position of the motor is greater than or equal to 1000.

```
GAP 1, 0, 0      //get axis parameter, type: no. 1 (actual position), motor: 0, value: 0 don't care
COMP 1000        //compare actual value to 1000
JC GE, Label     //jump, type: 5 greater/equal
...
...
Label: ROL 0, 1000
```

Binary format of JC GE, Label when Label is at address 10:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$15	$05	$00	$00	$00	$00	$0a

4.5.17 JA (jump always)

Jump to a fixed address in the TMCL program memory. This command is intended for standalone operation, only. The host address and the reply are required to take the instruction to the TMCL program memory while the TMCL program downloads. This command cannot be used in direct mode.

Internal function: The TMCL program counter is set to the passed value.

Related commands: JC, WAIT, CSUB

Mnemonic: JA <Label>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
22	don't care	don't care	<jump address>

Example:

An infinite loop in TMCL

```
Loop:   MVP ABS, 0, 10000
        WAIT POS, 0, 0
        MVP ABS, 0, 0
        WAIT POS, 0, 0
        JA Loop          //Jump to the label Loop
```

Binary format of JA Loop assuming that the label Loop is at address 20:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$16	$00	$00	$00	$00	$00	$14

4.5.18 CSUB (call subroutine) and RSUB (return from subroutine)

For implementing subroutines there are two commands:

- ***CSUB*** calls a subroutine in the TMCL program memory. It is intended for standalone operation, only.
  The host address and the reply are required to take the instruction to the TMCL program memory while the TMCL program downloads. *This command cannot be used in direct mode.*
- ***RSUB*** is used for returning from a subroutine to the next command behind the CSUB command.

Example: Call a subroutine

```
Loop:   MVP ABS, 0, 10000
        CSUB SubW       //Save program counter and jump to label SubW (see below)
        MVP ABS, 0, 0
        JA Loop

SubW:   WAIT POS, 0, 0
        WAIT TICKS, 0, 50
        RSUB            //Continue with the command following the CSUB command (in this example: MVP ABS).
```

4.5.18.1 CSUB (call subroutine)

Internal function: The actual TMCL program counter value is saved to an internal stack, afterwards overwritten with the passed value. The number of entries in the internal stack is limited to 8. This also limits nesting of subroutine calls to 8. The command will be ignored if there is no more stack space left.

Related commands: RSUB, JA

Mnemonic: CSUB <Label>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
23	don't care	don't care	<subroutine address>

Binary format of the CSUB SubW command assuming that the label SubW is at address 100:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$17	$00	$00	$00	$00	$00	$64

4.5.18.2 RSUB (return from subroutine)

Internal function: The TMCL program counter is set to the last value of the stack. The command will be ignored if the stack is empty.

Related command: CSUB

Mnemonic: RSUB

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
24	don't care	don't care	don't care

Binary format of RSUB:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$18	$00	$00	$00	$00	$00	$00

4.5.19 WAIT (wait for an event to occur)

This instruction interrupts the execution of the TMCL program until the specified condition is met. The WAIT command is intended for standalone operation only. The host address and the reply are used for communication with the TMCL memory. *This command is not to be used in direct mode.*

THERE ARE DIFFERENT WAIT CONDITIONS THAT CAN BE USED:

- TICKS: Wait until the number of timer ticks specified by the <ticks> parameter has been reached.
- POS: Wait until the target position of the motor specified by the <motor> parameter has been reached. An optional timeout value (0 for no timeout) must be specified by the <ticks> parameter.
- REFSW: Wait until the reference switch of the motor specified by the <motor> parameter has been triggered. An optional timeout value (0 for no timeout) must be specified by the <ticks> parameter.
- LIMSW: Wait until a limit switch of the motor specified by the <motor> parameter has been triggered. An optional timeout value (0 for no timeout) must be specified by the <ticks> parameter.
- RFS: Wait until the reference search of the motor specified by the <motor> field has been reached. An optional timeout value (0 for no timeout) must be specified by the <ticks> parameter.

The timeout flag (ETO) will be set after a timeout limit has been reached. You can then use a JC ETO command to check for such errors or clear the error using the CLE command.

Internal function: The TMCL program counter is held until the specified condition is met.

Related commands: JC, CLE

Mnemonic: WAIT <condition>, 0, <ticks>
where <condition> is TICKS|POS|REFSW|LIMSW|RFS

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
27	0 TICKS - timer ticks*1	don't care	<no. of ticks*>
	1 POS - target position reached	0	<no. of ticks* for timeout>, 0 for no timeout
	2 REFSW – reference switch	0	<no. of ticks* for timeout>, 0 for no timeout
	3 LIMSW – limit switch	0	<no. of ticks* for timeout>, 0 for no timeout
	4 RFS – reference search completed	0	<no. of ticks* for timeout>, 0 for no timeout

* One tick is 10msec (in standard firmware).

Example:
Wait for motor to reach its target position, without timeout
Mnemonic: WAIT POS, 0, 0

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$1b	$01	$01	$00	$00	$00	$00

4.5.20 STOP (stop TMCL program execution)

This function stops executing a TMCL program. The host address and the reply are only used to transfer the instruction to the TMCL program memory.

Every standalone TMCL program needs the STOP command at its end. It is not to be used in direct mode.

Internal function: TMCL instruction fetching is stopped.

Related commands: none

Mnemonic: STOP

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
28	don't care	don't care	don't care

Example:

Stop TMCL execution
Mnemonic: STOP

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$1c	$00	$00	$00	$00	$00	$00

4.5.21 CALCX (calculate using the X register)

This instruction is very similar to CALC, but the second operand comes from the X register. The X register can be loaded with the LOAD or the SWAP type of this instruction. The result is written back to the accumulator for further processing like comparisons or data transfer.

Related commands: CALC, COMP, JC, AAP, AGP

Mnemonic: CALCX <operation>

Binary representation:

COMMAND	TYPE <operation>	MOT/BANK	VALUE
33	0 ADD – add X register to accu 1 SUB – subtract X register from accu 2 MUL – multiply accu by X register 3 DIV – divide accu by X-register 4 MOD – modulo divide accu by x-register 5 AND – logical and accu with X-register 6 OR – logical or accu with X-register 7 XOR – logical exor accu with X-register 8 NOT – logical invert X-register 9 LOAD – load accu to X-register 10 SWAP – swap accu with X-register	don't care	don't care

Example:

Multiply accu by X-register
Mnemonic: CALCX MUL

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$21	$02	$00	$00	$00	$00	$00

4.5.22 AAP (accumulator to axis parameter)

The content of the accumulator register is transferred to the specified axis parameter. For practical use, the accumulator has to be loaded e.g. by a preceding GAP instruction. The accumulator may have been modified by the CALC or CALCX (calculate) instruction.

Related commands: AGP, SAP, GAP, SGP, GGP, CALC, CALCX

Mnemonic: AAP <parameter number>, 0

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
34	<parameter number>	0	<don't care>

Reply in direct mode:

STATUS	VALUE
100 – OK	don't care

See chapter 5 for a complete list of axis parameters.

Example:

Positioning a motor by a potentiometer connected to analogue input #0:

```
Start:  GIO 0, 1  // get value of analogue input line 0
        CALC MUL, 4       // multiply by 4
        AAP 0, 0  // transfer result to target position of motor 0
        JA Start  // jump back to start
```

Binary format of the AAP 0, 0 command:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$22	$00	$00	$00	$00	$00	$00

4.5.23 AGP (accumulator to global parameter)

The content of the accumulator register is transferred to the specified global parameter. For practical use, the accumulator has to be loaded e.g. by a preceding GAP instruction. The accumulator may have been modified by the CALC or CALCX (calculate) instruction.

- Note that the global parameters in bank 0 are mostly EEPROM-only and thus should not be modified automatically by a standalone application.
- See chapter 6 for a complete list of global parameters.

Related commands: AAP, SGP, GGP, SAP, GAP

Mnemonic: AGP <parameter number>, <bank number>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
35	<parameter number>	<bank number>	don't care

Reply in direct mode:

STATUS	VALUE
100 – OK	don't care

Example:

Copy accumulator to TMCL user variable #3
Mnemonic: AGP 3, 2

Binary:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Instruction Number	Type	Motor/ Bank	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$01	$23	$03	$02	$00	$00	$00	$00

4.5.24 Customer Specific TMCL Command Extension (user functions 0… 7)

The user definable functions UF0… UF7 are predefined functions without topic for user specific purposes. A user function UF command uses three parameters. Please contact TRINAMIC for a customer specific programming.

Internal function: Call user specific functions implemented in *C* by TRINAMIC.

Related commands: none

Mnemonic: UF0… UF7 <parameter number>

Binary representation:

COMMAND	TYPE	MOT/BANK	VALUE
64… 71	user defined	user defined	user defined

Reply in direct mode:

Byte Index	0	1	2	3	4	5	6	7
Function	Target-address	Target-address	Status	Instruction	Operand Byte3	Operand Byte2	Operand Byte1	Operand Byte0
Value (hex)	$02	$01	user defined	64… 71	user defined	user defined	user defined	user defined

4.5.25 Command 136 - Get Firmware Version

Command 136 is used for reading out the module type and firmware version as a string or in binary format. (*Motor/Bank* and *Value* are ignored.)

Other control functions can be used with axis parameters.

Command	Type	Parameter	Description	Access
136	0 – string 1 – binary	Firmware version	Get the module type and firmware revision as a string or in binary format. (*Motor/Bank* and *Value* are ignored.)	read

TYPE SET TO 0 - REPLY AS A STRING:

Byte index	Contents
1	Host Address
2… 9	Version string (8 characters, e.g. 1640V200)

There is no checksum in this reply format!

TYPE SET TO 1 - VERSION NUMBER IN BINARY FORMAT:

The version number is output in the *value* field.

Byte index in value field	Contents
1	Version number, low byte
2	Version number, high byte
3	Type number, low byte
4	Type number, high byte

5 Axis Parameter Overview (SAP, GAP, STAP, RSAP, AAP)

The following section describes all axis parameters that can be used with the SAP, GAP, STAP, RSAP and AAP commands.

MEANING OF THE LETTERS IN COLUMN *ACCESS*:

Access type	Related command(s)	Description
R	GAP	Parameter readable
W	SAP, AAP	Parameter writable
E	STAP, RSAP	Parameter automatically restored from EEPROM after reset or power-on. These parameters can be stored permanently in EEPROM using STAP command and also explicitly restored (copied back from EEPROM into RAM) using RSAP.

Number	Axis Parameter	Description	Range [Unit]	Access
0	Target position	The target position of a currently executed ramp.	-2147483648… +2147483647	RW
1	Actual position	Set/get the position counter without moving the motor.	-2147483648… +2147483647	RW
2	Target speed	Set/get the desired target velocity.	-200000… +200000 [rpm]	RW
3	Actual speed	The actual velocity of the motor.	-2147483648… +2147483647 [rpm]	R
4	Max. absolute ramp velocity	The maximum velocity used for velocity ramp in velocity mode and positioning mode. Set this value to a realistic velocity which the motor can reach!	0 +200000 [rpm]	RWE
6	Max current	Set/get the max allowed motor current. *This value can be temporarily exceeded marginal due to the operation of the current regulator.	0… +20000 [mA]	RWE
7	MVP Target reached velocity	Maximum velocity at which end position flag can be set. Prevents issuing of end position when the target is passed at high velocity.	0 +200000 [rpm]	RWE
9	Motor halted velocity	If the actual speed is below this value the motor halted flag will be set.	0 +200000 [rpm]	RWE
10	MVP target reached distance	Maximum distance at which the position end flag is set.	0… +100000	RWE
11	Acceleration	Acceleration parameter for ROL, ROR, and the velocity ramp of MVP.	0… +100000 [RPM/s]	RWE
13	Ramp generator speed	The actual speed of the velocity ramp used for positioning and velocity mode.	-2147483648… +2147483647 [rpm]	R
25	Thermal winding time constant	Thermal winding time constant for the used motor. Used for I²t monitoring.	0… +4294967295 [ms]	RWE
26	I²t limit	An actual I²t sum that exceeds this limit leads to increasing the I²t exceed counter.	0… +4294967295	RWE
27	I²t sum	Actual sum of the I²t monitor.	0… +4294967295	R
28	I²t exceed counter	Counts how often an I²t sum was higher than the I²t limit.	0… +4294967295	RWE
29	Clear I²t exceeded flag	Clear the flag that indicates that the I²t sum has exceeded the I²t limit.	(ignored)	W
30	Minute counter	Counts the module operational time in minutes.	0… +4294967295 [min]	RWE
31	BLDC re-initialization	Restart the timer and initialize encoder.	(ignored)	W
133	PID regulation loop delay	Delay of the position and velocity	0… +10 [ms]	RWE
134	Current regulation loop delay	Delay of the PID current regulator.	0… +10 [50µs]	RWE
146	Activate ramp	1: Activate velocity ramp generator for position and velocity mode. (Allows usage of acceleration and positioning velocity for MVP command.)	0/1	RWE
150	Actual motor current	Get actual motor current.	-2147483648… +2147483647 [mA]	R

Number	Axis Parameter	Description	Range [Unit]	Access
151	Actual voltage	Actual supply voltage.	0… +4294967295	R
152	Actual driver temperature	Actual temperature of the motor driver.	0… +4294967295	R
155	Target current	Get desired target current or set target current to activate current regulation mode. (+= turn motor in right direction; -= turn motor in left direction)	-20000… +20000 [mA]	RW
156	Error/Status flags	Bit 0: Overcurrent flag. This flag is set if the max. current limit is exceeded. Bit 1: Undervoltage flag. This flag is set if supply voltage is too low for motor operation. Bit 2: Overvoltage flag. This flag is set if the motor becomes switched off due to overvoltage. Bit 3: Overtemperature flag. This flag is set if overtemperature limit is exceeded. Bit 4: Motor halted flag. This flag is set if motor has been switched off. Bit 5: Hall error flag. This flag is set upon a hall error. Bit 6: TMC603 error flag Bit 7: unused Bit 8: unused Bit 9: Velocity mode active flag Bit 10: Position mode active flag. Bit 11: Torque mode active flag. Bit 12: unused Bit 13: unused Bit 14: Position end flag. This flag is set if the motor has been stopped at the target position. Bit 15: Module initialized Bit 16: unused Bit 17: I^2t exceeded flag. This flag is set if the I^2t sum exceeded the I^2t limit of the motor. (reset by SAP 29 after the time specified by the I^2t thermal winding time constant) *Flag 0 to 15 are automatically reset. Only flag 17 must be cleared manually.*	0…+4294967295	R
159	Commutation mode	0: Block based on hall sensor 6: FOC based on hall sensor 7: FOC based on encoder 8: FOC controlled (velocity mode only)	0, 6, 7, 8	RWE
161	Encoder set NULL	1: set position counter to zero at next N channel event.	0/1	RWE
162	Switch set NULL	1: set position counter to zero at next switch event.	0/1	RWE
163	Encoder clear set NULL	1: set position counter to zero only once 0: always at an N channel event	0/1	RWE
164	Activate stop switch	Bit 0 — Left stop switch enable — When this bit is set the motor will be stopped if it is moving in negative direction and the left stop switch input becomes active Bit 1 — Right stop switch enable — When this bit is set the motor will be stopped if it is moving in positive direction and the right stop switch input becomes active Please see parameter 166 for selecting the stop switch input polarity.	0… 3	RWE
165	Actual encoder commutation offset	This value represents the internal commutation offset. (0 … max. encoder steps per rotation)	0… 65535	RWE

Number	Axis Parameter	Description			Range [Unit]	Access
166	Stop switch polarity	Bit 0	Left stop switch polarity	Bit set: Left stop switch input is high active Bit clear: Left stop switch input is low active	0… 3	RWE
		Bit 1	Right stop switch polarity	Bit set: Right stop switch input is high active Bit clear: Right stop switch input is low active		
172	P parameter for current PID	P parameter of current PID regulator.			0… 65535	RWE
173	I parameter for current PID	I parameter of current PID regulator.			0… 65535	RWE
177	Start current	Motor current for controlled commutation. This parameter is used in commutation mode.			0… +20000 [mA]	RWE
200	Current PID error	Actual error of current PID regulator			-2147483648… +2147483647	R
201	Current PID error sum	Sum of errors of current PID regulator			-2147483648… +2147483647	R
210	Actual hall angle	Actual hall angle value			-32767… +32767	R
211	Actual encoder angle	Actual encoder angle value			-32767… +32767	R
212	Actual controlled angle	Actual controlled angle value			-32767… +32767	R
226	Position PID error	Actual error of position PID regulator			-2147483648… +2147483647	R
228	Velocity PID error	Actual error of velocity PID regulator			-2147483648… +2147483647	R
229	Velocity PID error sum	Sum of errors of velocity PID regulator			-2147483648… +2147483647	R
230	P parameter for position PID	P parameter of position PID regulator.			0… 65535	RWE
234	P parameter for velocity PID	P parameter of velocity PID regulator.			0… 65535	RWE
235	I parameter for velocity PID	I parameter of velocity PID regulator.			0… 65535	RWE
241	Sine initialization speed	Velocity during initialization in init sine mode 2. Refer to axis parameter 249, too.			-200000… +200000 [rpm]	RWE
244	Init sine delay	Duration for sine initialization sequence. This parameter should be set in a way, that the motor has stopped mechanical oscillations after the specified time.			0… 10000 [ms]	RWE
245	Overvoltage protection	1: Enable overvoltage protection.			0/1	RWE
249	Init sine mode	0: Initialization in controlled sine commutation (determines the encoder offset) 1: Initialization in block commutation using hall sensors 2: Initialization in controlled sine commutation (use the previous set encoder offset)			0, 1, 2	RWE
250	Encoder steps	Encoder steps per rotation.			0… +65535	RWE
251	Encoder direction	Set the encoder direction in a way, that ROR increases position counter.			0/1	RWE
253	Number of motor poles	Number of motor poles.			+2… +254	RWE
254	Hall sensor invert	1: Hall sensor invert. Invert the hall scheme, e.g. used by some Maxon motors.			0/1	RWE
255	Enable driver	Enable or disable the driver and switch to stop mode. 0: Disable driver 1: Enable driver			0/1	RW

5.1 Axis Parameter Sorted by Functionality

The following section describes all axis parameters that can be used with the SAP, GAP, STAP, RSAP and AAP commands.

MEANING OF THE LETTERS IN COLUMN *ACCESS*:

Access type	Related command(s)	Description
R	GAP	Parameter readable
W	SAP, AAP	Parameter writable
E	STAP, RSAP	Parameter automatically restored from EEPROM after reset or power-on. These parameters can be stored permanently in EEPROM using STAP command and also explicitly restored (copied back from EEPROM into RAM) using RSAP.

MOTOR / MODULE SETTINGS

Number	Axis Parameter	Description	Range [Unit]	Access
253	Number of motor poles	Number of motor poles.	+2… +254	RWE
25	Thermal winding time constant	Thermal winding time constant for the used motor. Used for I²t monitoring.	0… +4294967295 [ms]	RWE
26	I²t limit	An actual I²t sum that exceeds this limit leads to increasing the I²t exceed counter.	0… +4294967295	RWE
27	I²t sum	Actual sum of the I²t monitor.	0… +4294967295	R
28	I²t exceed counter	Counts how often an I²t sum was higher than the I²t limit.	0… +4294967295	RWE
29	Clear I²t exceeded flag	Clear the flag that indicates that the I²t sum has exceeded the I²t limit.	(ignored)	W
30	Minute counter	Counts the module operational time in minutes.	0… +4294967295 [min]	RWE
245	Overvoltage protection	1: Enable overvoltage protection.	0/1	RWE
255	Enable driver	Enable or disable the driver and switch to stop mode. 0: Disable driver 1: Enable driver	0/1	RW

ENCODER / INITIALIZATION SETTINGS

Number	Axis Parameter	Description	Range [Unit]	Access
31	BLDC re-initialization	1: restart the timer and initialize encoder.	(Ignored)	W
159	Commutation mode	0: Block based on hall sensor 6: FOC based on hall sensor 7: FOC based on encoder 8: FOC controlled (velocity mode only)	0, 6, 7, 8	RWE
165	Actual encoder commutation offset	This value represents the internal commutation offset. (0 … max. encoder steps per rotation)	0… 65535	RWE
177	Start current	Motor current for controlled commutation. This parameter is used in commutation mode.	0… +20000 [mA]	RWE
210	Actual hall angle	Actual hall angle value	-32767… +32767	R
211	Actual encoder angle	Actual encoder angle value	-32767… +32767	R
212	Actual controlled angle	Actual controlled angle value	-32767… +32767	R
241	Sine initialization speed	Velocity during initialization in init sine mode 2. Refer to axis parameter 249, too.	-200000… +200000 [rpm]	RWE
244	Init sine delay	Duration for sine initialization sequence. This parameter should be set in a way, that the motor has stopped mechanical oscillations after the specified time.	0… 10000 [ms]	RWE
249	Init sine mode	0: Initialization in controlled sine commutation (determines the encoder offset) 1: Initialization in block commutation using hall sensors 2: Initialization in controlled sine commutation (use the previous set encoder offset)	0… 2	RWE
250	Encoder steps	Encoder steps per rotation.	0… +65535	RWE

Number	Axis Parameter	Description	Range [Unit]	Access
251	Encoder direction	Set the encoder direction in a way, that ROR increases position counter.	0/1	RWE
254	Hall sensor invert	1: Hall sensor invert. Invert the hall scheme, e.g. used by some Maxon motors.	0/1	RWE

TORQUE REGULATION MODE

Number	Axis Parameter	Description	Range [Unit]	Access
6	Max current	Set/get the max allowed motor current. This value can be temporarily exceeded marginal due to the operation of the current regulator.	0… +20000 [mA]	RWE
150	Actual motor current	Get actual motor current.	-2147483648… +2147483647 [mA]	R
155	Target current	Get desired target current or set target current to activate current regulation mode. (+= turn motor in right direction; -= turn motor in left direction)	-20000… +20000 [mA]	RW
134	Current regulation loop delay	Delay of the PID current regulator.	0… +10 [50µs]	RWE
172	P parameter for current PID	P parameter of current PID regulator.	0… 65535	RWE
173	I parameter for current PID	I parameter of current PID regulator.	0… 65535	RWE
200	Current PID error	Actual error of current PID regulator	-2147483648… +2147483647	R
201	Current PID error sum	Sum of errors of current PID regulator	-2147483648… +2147483647	R

VELOCITY REGULATION MODE

Number	Axis Parameter	Description	Range [Unit]	Access
2	Target speed	Set/get the desired target velocity.	-2147483648… +2147483647 [rpm]	RW
3	Actual speed	The actual velocity of the motor.	-2147483648… +2147483647 [rpm]	R
9	Motor halted velocity	If the actual speed is below this value the motor halted flag will be set.	0 +200000 [rpm]	RWE
133	PID regulation loop delay	Delay of the position and velocity	0… +10 [ms]	RWE
234	P parameter for velocity PID	P parameter of velocity PID regulator.	0… 65535	RWE
235	I parameter for velocity PID	I parameter of velocity PID regulator.	0… 65535	RWE
228	Velocity PID error	Actual error of PID velocity regulator	-2147483648… +2147483647	R
229	Velocity PID error sum	Sum of errors of PID velocity regulator	-2147483648… +2147483647	R

VELOCITY RAMP PARAMETER

Number	Axis Parameter	Description	Range [Unit]	Access
4	Max. absolute ramp velocity	The maximum velocity used for velocity ramp in velocity mode and positioning mode. Set this value to a realistic velocity which the motor can reach!	0 +200000 [rpm]	RWE
11	Acceleration	Acceleration parameter for ROL, ROR, and the velocity ramp of MVP.	0… +100000 [RPM/s]	RWE
13	Ramp generator speed	The actual speed of the velocity ramp used for positioning and velocity mode.	-2147483648… +2147483647 [rpm]	R
146	Activate ramp	1: Activate velocity ramp generator for position PID control. (Allows usage of acceleration and positioning velocity for MVP command.)	0/1	RWE

POSITION REGULATION MODE

Number	Axis Parameter	Description	Range [Unit]	Access
1	Actual position	Set/get the position counter without moving the motor.	-2147483648… +2147483647	RW
0	Target position	The target position of a currently executed ramp.	-2147483648… +2147483647	RW
7	MVP Target reached velocity	Maximum velocity at which end position flag can be set. Prevents issuing of end position when the target is passed at high velocity.	0 +200000 [rpm]	RWE
10	MVP target reached distance	Maximum distance at which the position end flag is set.	0… +100000	RWE
161	Encoder set NULL	1: set position counter to zero at next N channel event.	0/1	RWE
162	Switch set NULL	1: set position counter to zero at next switch event.	0/1	RWE
163	Encoder clear set NULL	1: set position counter to zero only once 0: always at an N channel event	0/1	RWEP
164	Activate stop switch	Bit 0 – Left stop switch enable – When this bit is set the motor will be stopped if it is moving in negative direction and the left stop switch input becomes active Bit 1 – Right stop switch enable – When this bit is set the motor will be stopped if it is moving in positive direction and the right stop switch input becomes active Please see parameter 166 for selecting the stop switch input polarity.	0… 3	RWE
166	Stop switch polarity	Bit 0 – Left stop switch polarity – Bit set: Left stop switch input is high active Bit clear: Left stop switch input is low active Bit 1 – Right stop switch polarity – Bit set: Right stop switch input is high active Bit clear: Right stop switch input is low active	0… 3	RWE
230	P parameter for position PID	P parameter of position PID regulator. (	0… 65535	RWE
226	Position PID error	Actual error of PID position regulator	-2147483648… +2147483647	R

STATUS INFORMATION

Number	Axis Parameter	Description	Range [Unit]	Access
151	Actual voltage	Actual supply voltage.	0… +4294967295	R
152	Actual driver temperature	Actual temperature of the motor driver.	0… +4294967295	R

Number	Axis Parameter	Description	Range [Unit]	Access
156	Error/Status flags	Bit 0: Overcurrent flag. This flag is set if the max. current limit is exceeded. Bit 1: Undervoltage flag. This flag is set if supply voltage is too low for motor operation. Bit 2: Overvoltage flag. This flag is set if the motor becomes switched off due to overvoltage. Bit 3: Overtemperature flag. This flag is set if overtemperature limit is exceeded. Bit 4: Motor halted flag. This flag is set if motor has been switched off. Bit 5: Hall error flag. This flag is set upon a hall error. Bit 6: TMC603 error flag Bit 7: unused Bit 8: unused Bit 9: Velocity mode active flag Bit 10: Position mode active flag. Bit 11: Torque mode active flag. Bit 12: unused Bit 13: unused Bit 14: Position end flag. This flag is set if the motor has been stopped at the target position. Bit 15: Module initialized Bit 16: unused Bit 17: I^2t exceeded flag. This flag is set if the I^2t sum exceeded the I^2t limit of the motor. (reset by SAP 29 after the time specified by the I^2t thermal winding time constant) *Flag 0 to 15 are automatically reset. Only flag 17 must be cleared manually.*	0…+4294967295	R

6 Global Parameter Overview (SGP, GGP, STGP, RSGP, AGP)

The following section describes all global parameters that can be used with the SGP, GGP, STGP and RSGP commands.

TWO BANKS ARE USED FOR GLOBAL PARAMETERS:

- Bank 0 (global configuration of the module)
- Bank 2 (user TMCL variables)

6.1 Bank 0

Parameters 64… 255

Parameters below 63 configure stuff like the serial address of the module RS485 baud rate or the telegram pause time. Change these parameters to meet your needs. The best and easiest way to do this is to use the appropriate functions of the TMCL-IDE. The parameters between 64 and 85 are stored in EEPROM only. A SGP command on such a parameter will always store it permanently and no extra STGP command is needed.

Take care when changing these parameters and use the appropriate functions of the TMCL-IDE to do it in an interactive way!

MEANING OF THE LETTERS IN COLUMN *ACCESS*:

Access type	Related command(s)	Description
R	GGP	Parameter readable
W	SGP, AGP	Parameter writable
E	STGP, RSGP	Parameter automatically restored from EEPROM after reset or power-on.

GLOBAL PARAMETERS OF BANK 0

Number	Global parameter	Description	Range	Access
64	EEPROM magic	Setting this parameter to a different value as $E4 will cause re-initialization of the axis and global parameters (to factory defaults) after the next power up. This is useful in case of miss-configuration.	0… 255	RWE
65	RS485 baud rate	0 – 9600 baud – *Default* 1 – 14400 baud 2 – 19200 baud 3 – 28800 baud 4 – 38400 baud 5 – 57600 baud 6 – 76800 baud – *Not supported by Windows!* 7 – 115200 baud	0… 7	RWE
66	Serial address	The module (target) address for RS485 and virtual COM port	0… 255	RWE
73	Configuration EEPROM lock flag	Write: 1234 to lock the EEPROM, 4321 to unlock it. Read: 1=EEPROM locked, 0=EEPROM unlocked.	0/1	RWE
75	Telegram pause time	Pause time before the reply via RS485 is sent.	0… 255	RWE
76	Serial host address	Host address used in the reply telegrams sent back via RS485.	0… 255	RWE
77	Auto start mode	0: Do not start TMCL application after power up (*default*). 1: Start TMCL application automatically after power up. *Note: the current initialization has to be finished first.*	0/1	RWE
81	TMCL code protection	Protect a TMCL program against disassembling or overwriting. 0 – no protection 1 – protection against disassembling 2 – protection against overwriting 3 – protection against disassembling and overwriting *If you switch off the protection against disassembling, the program will be erased first!* *Changing this value from 1 or 3 to 0 or 2, the TMCL program will be wiped off.*	0, 1, 2, 3	RWE
85	Do not restore user variables	0 – user variables are restored (*default*) 1 – user variables are not restored	0/1	RWE
128	TMCL application status	0 –stop 1 – run 2 – step 3 – reset	0… 3	R

Number	Global parameter	Description	Range	Access
129	Download mode	0 – normal mode 1 – download mode *Attention:* *Download mode can only be used if the motor has been stopped first. Otherwise the download mode setting will be disallowed.* *During download mode the motor driver will be deactivated and the actuator will be turned off.*	0/1	R
130	TMCL program counter	The index of the currently executed TMCL instruction.	o… 2047	R
132	Tick timer	A 32 bit counter that gets incremented by one every millisecond. It can also be reset to any start value.	0… +4294967295	RW
255	Suppress reply	0 – reply (*default*) 1 – no reply	0/1	RW

6.2 Bank 2

Bank 2 contains general purpose 32 bit variables for the use in TMCL applications. They are located in RAM and can be stored to EEPROM. After booting, their values are automatically restored to the RAM.

Up to 256 user variables are available.

MEANING OF THE LETTERS IN COLUMN *ACCESS*:

Access type	Related command(s)	Description
R	GGP	Parameter readable
W	SGP, AGP	Parameter writable
E	STGP, RSGP	Parameter automatically restored from EEPROM after reset or power-on.

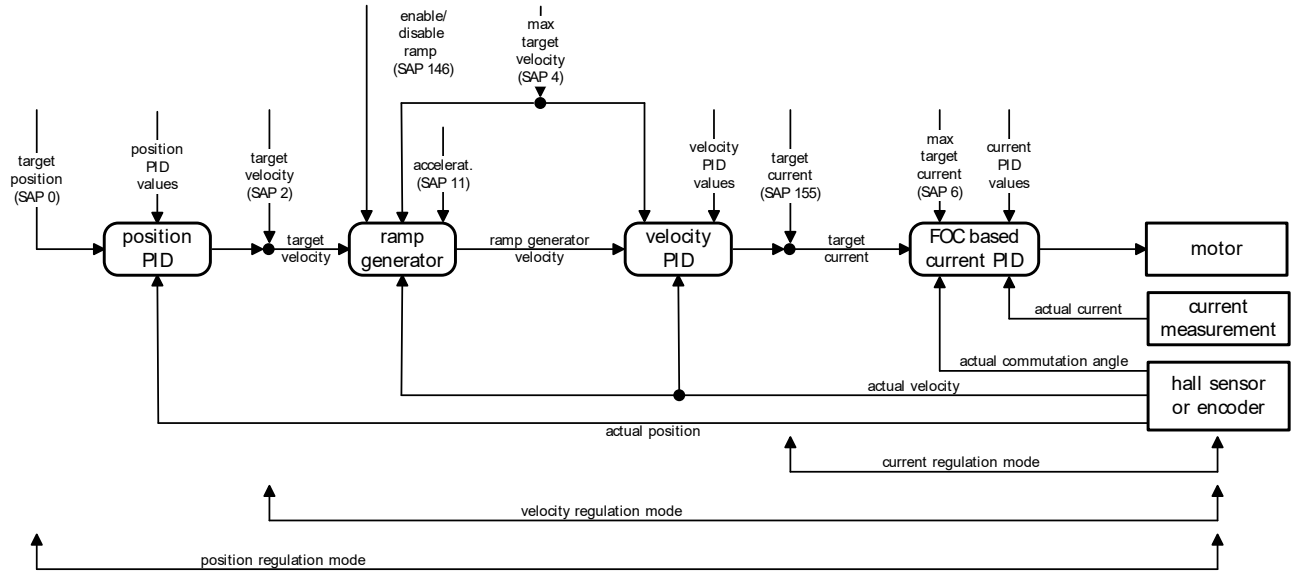
GLOBAL PARAMETERS OF BANK 2

Number	Global parameter	Description	Range	Access
0… 55	General purpose variable #0… 55	for use in TMCL applications	-2^{31}…$+2^{31}$ (int32)	RWE
56… 255	General purpose variables #56… #255	for use in TMCL applications	-2^{31}…$+2^{31}$ (int32)	RW

7 Motor Regulation

7.1 Structure of the Cascaded Motor Regulation Modes

The TMCM-1640 supports a current, velocity, and position PID regulation mode for motor control in different application areas. These regulation modes are cascaded as shown in figure 12.1. The individual modes are explained in the following sections.



7.1 Cascaded regulation

7.2 Current Regulation

The current regulation mode uses a PID regulator to adjust a desired motor current. This target current can be set by axis parameter 155. The maximal target current is limited by axis parameter 6.

The PID regulation uses three basic parameters: The *P* and *I* value as well as the *timing control value*.

TIMING CONTROL VALUE

The timing control value (*current regulation loop multiplier*, axis parameter 134) determines how often the current regulation is invoked. It is given in multiple of 50µs:

$$t_{PIDDELAY} = x_{PIDRLD} \cdot 50\mu s$$

$t_{PIDDELAY}$ = resulting delay between two current regulation loops
x_{PIDRLD} = *current regulation loop multiplier* parameter

For most applications it is recommended to leave this parameter unchanged at its default of 2*50µs. Higher values may be necessary for very slow and less dynamic drives.

STRUCTURE OF THE CURRENT REGULATOR

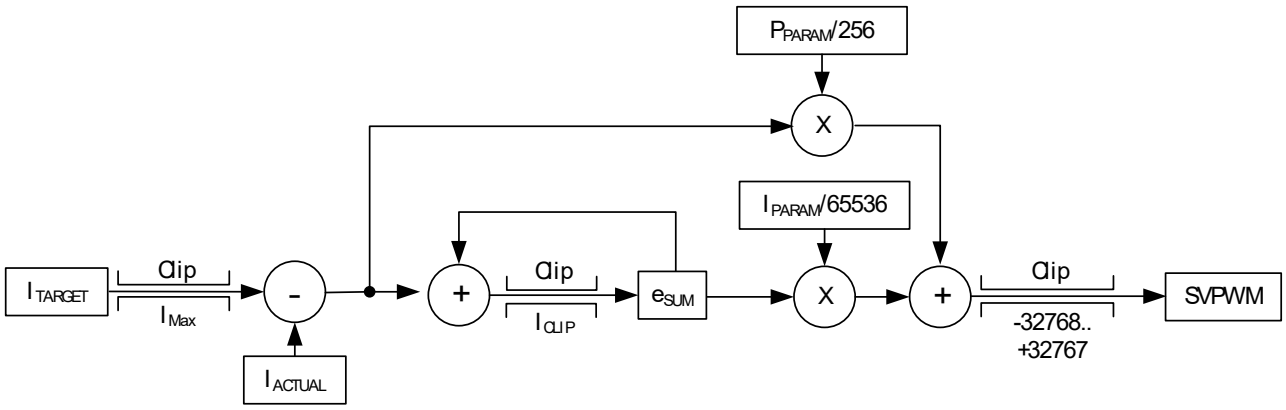


Figure 7.2 Current regulation

Parameter	Description
I_{ACTUAL}	Actual motor current (GAP 150)
I_{TARGET}	Target motor current (SAP 155)
I_{Max}	Max. motor current (SAP 6)
e_{SUM}	Error sum for integral calculation (GAP 201)
P_{PARAM}	Current P parameter (SAP 172)
I_{PARAM}	Current I parameter (SAP 173)

PARAMETERIZING THE CURRENT REGULATOR SET

1. Set the *P* parameter and the *I* parameter to zero.
2. Start the motor by using a low target current (e.g. 1000 mA).
3. Modify the current *P* parameter. Start from a low value and go to a higher value, until the actual current nearly reaches 50% of the desired target current.
4. Do the same with the current *I* parameter.

For all tests set the motor current limitation to a realistic value, so that your power supply does not become overloaded during acceleration phases. If your power supply reaches current limitation, the unit may reset or undetermined regulation results may occur.

7.3 Velocity Regulation

Based on the current regulation the motor velocity can be controlled by the velocity PID regulator.

TIMING CONTROL VALUE

Also, the velocity PID regulator uses a timing control value (*PID regulation loop delay*, axis parameter 133) which determines how often the PID regulator is invoked. It is given in multiple of 1ms:

$$t_{PIDDELAY} = x_{PIDRLD} \cdot 1\text{ms}$$

$t_{PIDDELAY}$ = resulting delay between two PID calculations
x_{PIDRLD} = *PID regulation loop delay* parameter

For most applications it is recommended to leave this parameter unchanged at its default value of 1ms.
Higher values may be necessary for very slow and less dynamic drives.

STRUCTURE OF THE VELOCITY REGULATOR

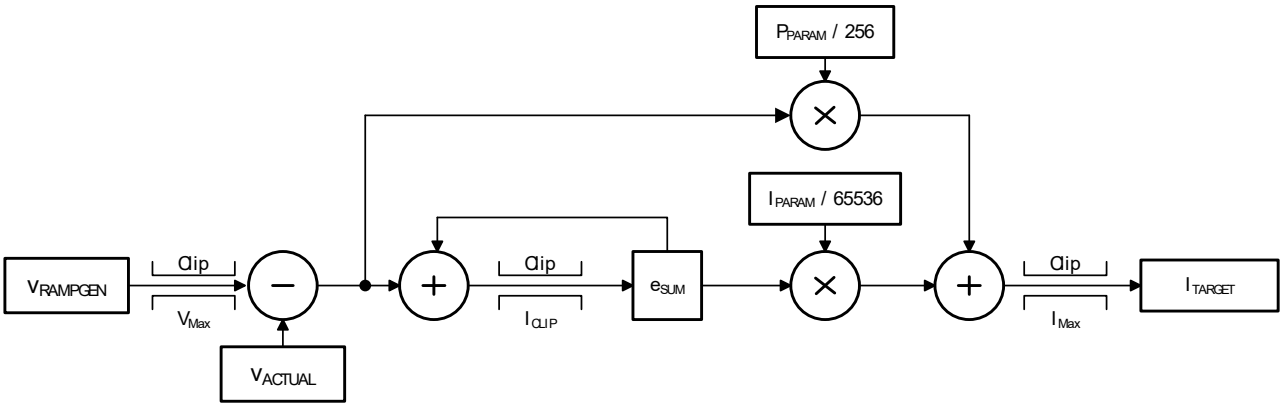


Figure 7.3 Velocity regulation

Parameter	Description
v_{ACTUAL}	Actual motor velocity (GAP 3)
$v_{RAMPGEN}$	Target velocity of ramp generator (SAP 2, GAP 13)
v_{Max}	Max. target velocity (SAP 4)
e_{SUM}	Error sum for integral calculation (GAP 229)
P_{PARAM}	Velocity P parameter (SAP 234)
I_{PARAM}	Velocity I parameter (SAP 235)
I_{Max}	Max. target current (SAP 6)
I_{Target}	Target current for current PID regulator (GAP 155)

PARAMETERIZING THE VELOCITY REGULATOR SET

1. Set the *velocity I parameter* to zero.
2. Start the motor by using a medium target velocity (e.g. 2000 rpm).
3. Modify the *velocity P parameter*. Start from a low value and go to a higher value, until the actual motor speed reaches 80 or 90% of the target velocity.
4. The lasting 10 or 20% speed difference can be reduced by slowly increasing the *velocity I parameter*.

7.4 Velocity Ramp Generator

For a controlled start up of the motor's velocity a velocity ramp generator can be activated/deactivated by axis parameter 146. The ramp generator uses the maximal allowed motor velocity (axis parameter 4), the acceleration (axis parameter 11) und the desired target velocity (axis parameter 2) to calculate a ramp generator velocity for the following velocity PID regulator.

7.5 Position Regulation

Based on current and velocity regulators the TMCM-1640 supports a positioning mode based on encoder or hall sensor position. During positioning the velocity ramp generator can be activated to enable motor positioning with controlled acceleration or it can be disabled to support motor positioning with max allowed speed.

The PID regulation uses two basic parameters: the *P* regulation and a timing control value.

TIMING CONTROL VALUE

The timing control value (*PID regulation loop parameter* - axis parameter 133) determines how often the PID regulator is invoked. It is given in multiple of 1ms:

$$t_{PIDDELAY} = x_{PIDRLD} \cdot 1\text{ms}$$

$t_{PIDDELAY}$ = the resulting delay between two position regulation loops

x_{PIDRLD} = *PID regulation loop multiplier* parameter

For most applications it is recommended to leave the timing control value unchanged at its default of 1ms. Higher values may be necessary for very slow and less dynamic drives.

STRUCTURE OF THE POSITION REGULATOR

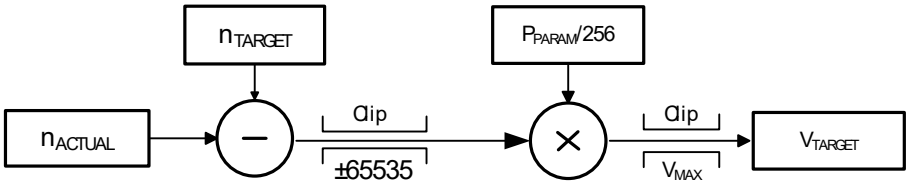


Figure 7.4 Positioning regulation

Parameter	Description
n_{ACTUAL}	Actual motor position (GAP 1)
n_{TARGET}	Target motor position (SAP 0)
P_{PARAM}	Position P parameter (SAP 130, SAP 230)
V_{MAX}	Max. allowed velocity (SAP 4)
V_{TARGET}	New target velocity for ramp generator (GAP 13)

PARAMETERIZING THE POSITION REGULATION

Based on the velocity regulator only the position regulator P has to be parameterized.

1. Disable the velocity ramp generator and set position *P* parameter to zero.
2. Choose a target position and increase the position *P* parameter until the motor reaches the target position approximately.
3. Switch on the *velocity ramp generator*. Based on the *max. positioning velocity* (axis parameter 4) and the *acceleration value* (axis parameter 11) the ramp generator automatically calculates the *slow down point*, i.e. the point at which the velocity has to be reduced in order to stop at the desired target position.
4. Reaching the target position is signaled by setting the *position end flag*.

NOTE:

- In order to minimize the time until this flag becomes set, the positioning tolerance *MVP target reached distance* can be chosen with axis parameter 10.
- Since the motor typically is assumed not to signal target reached when the target was just passed in a short moment at a high velocity, additionally the maximum target reached velocity (*MVP target reached velocity)* can be defined by axis parameter 7.
- A value of zero for axis parameter 7 is the most universal, since it implies that the motor stands still at the target. But when a fast rising of the *position end flag* is desired, a higher value for the *MVP target reached velocity* parameter will save a lot of time. The best value should be tried out in the actual application.

CORRELATION OF AXIS PARAMETERS 10 AND 7, THE TARGET POSITION, AND THE POSITION END FLAG

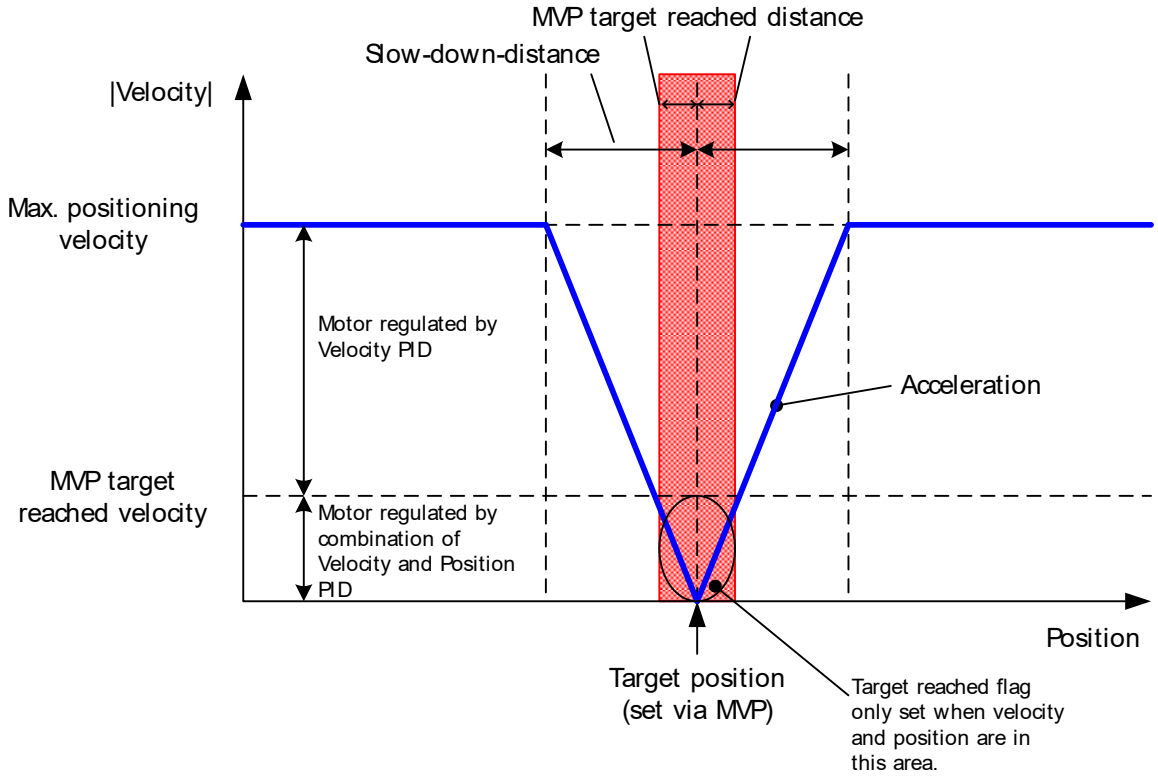


Figure 7.5 Positioning algorithm

Depending on motor and mechanics a low oscillation is normal. This can be reduced to at least +/-1 encoder steps. Without oscillation the regulation cannot keep the position!

8 Temperature Calculation

Axis parameter 152 delivers the actual ADC value of the motor driver. This ADC value can be converted to a temperature in °C as follows:

$$\text{ADC} = actual\ value\ of\ GAP\ 152$$

$$\text{B} = 3434\ (material\ constant)$$

$$\text{R}_{\text{NTC}} = \frac{9011{,}2}{ADC} - 2.2$$

$$\text{T} = \frac{B * 298{,}16}{B + (\ln\left(\frac{R_{NTC}}{10}\right) * 298.16} - 273.16\ °C$$

Example 1:
ADC = 1000
$R_{NTC} \approx 6.81$
$T \approx 35\,°C$

Example 2:
ADC = 1200
$R_{NTC} \approx 5.31$
$T \approx 42\,°C$

9 I²t Monitoring

The I²t monitor determines the sum of the square of the motor current over a given time. The integrating time is motor specific. In the datasheet of the motor this time is described as *thermal winding time constant* and can be set for each module using axis parameter 25. The number of measurement values within this time depends on how often the current regulation and thus the I²t monitoring is invoked. The value of the actual I²t sum can be read by axis parameter 27. With axis parameter 26 the default value for the I²t limit can be changed (default: 211200). If the actual I²t sum exceeds the I²t limit of the motor, flag 17 (in axis parameter 156) is set and the motor pwm is set to zero as long as the I²t exceed flag is set. The actual regulation mode will not be changed. Furthermore, the I²t exceed counter is increased once every second as long as the actual I²t sum exceeds the I²t limit. The I²t exceed flag can be cleared manually using parameter 29 but only after the cool down time given by the *thermal winding time constant* has passed. The I²t exceed flag will not be reset automatically. The I²t limit can be determined as follows:

$$I^2t = \frac{I\ [mA]}{1000} * \frac{I\ [mA]}{1000} * t_{tw}\ [ms]$$

I is the desired average current
t_{tw} is the thermal winding time constant given by the motor datasheet

Example:

I²t limits for an average current of a) 1A, b) 2A, c) 3A and d) 4A over a thermal winding time of 13,2s.

a) $I^2t\ limit = \frac{1000\ [mA]}{1000} * \frac{1000\ [mA]}{1000} * 13200\ [ms] = 13200\ [mA^2 * ms]$

b) $I^2t\ limit = \frac{2000\ [mA]}{1000} * \frac{2000\ [mA]}{1000} * 13200\ [ms] = 52800\ [mA^2 * ms]$

c) $I^2t\ limit = \frac{3000\ [mA]}{1000} * \frac{3000\ [mA]}{1000} * 13200\ [ms] = 118800\ [mA^2 * ms]$

d) $I^2t\ limit = \frac{4000\ [mA]}{1000} * \frac{4000\ [mA]}{1000} * 13200\ [ms] = 211200\ [mA^2 * ms]$

10 Life Support Policy

TRINAMIC Motion Control GmbH & Co. KG does not authorize or warrant any of its products for use in life support systems, without the specific written consent of TRINAMIC Motion Control GmbH & Co. KG.

Life support systems are equipment intended to support or sustain life, and whose failure to perform, when properly used in accordance with instructions provided, can be reasonably expected to result in personal injury or death.

11 Revision History

11.1 Firmware Revision

Version	Date	Author	Description
2.00	2012-JUN-10	ED	New FOC firmware
2.02	2012-DEC-14	ED	- Axis parameter 209 deleted. - Axis parameter 241 (sine initialization speed) added. - Axis parameter 31 (BLDC re-initialization) added. - Global parameter 77 (auto start mode) updated. - Global parameter 129 (download mode) updated.
2.05	2013-APR-03	ED	- Several axis parameter values updated. - Axis parameter 159 updated: new FOC controlled mode. - Axis parameter 212 (actual controlled angle) new.
2.06	2013-AUG-30	ED	- Bug fixed: adc offset calibration on power on - Bug fixed: encoder initialisation in encoder-init-mode 1 with inverted hall sensor signals - AP 238 removed (mass inertia const) - AP 239 removed (BEMF const) - AP 240 removed (motor coil resistance)
2.08	2016-FEB-16	ED	- removed motor noise when using telegram-pause-time - added Block-Hall commutation mode - added getter for Phase_A, Phase_B, Phase_C, VSupply, and Temp adc values - ignore module address when using USB connection (module remains always accessible) - allow encoder initialization in positioning mode - updated USB-VID/-PID
2.09	2018-FEB-08	ED	- Encoder-Init-Mode-0 stores N-channel offset synchronized with EEPROM-access of TMCL script.
2.10	2020-JAN-31	ED	- Axis parameter 255 (enable driver) added.

11.2 Document Revision

Version	Date	Author	Description
2.00	2012-JUL-31	SD	Manual for new *Field Orientated Control* (FOC) firmware - Commands SIO and GIO added - Axis parameters updated - Motor regulation updated
2.01	2013-JAN-03	SD	- Axis parameter 209 deleted. - Axis parameter 241 (sine initialization speed) added. - Axis parameter 31 (BLDC re-initialization) added. - Global parameter 77 (auto start mode) updated. - Global parameter 129 (download mode) updated.
2.02	2013-APR-04	SD	- Several axis parameter values updated. - Axis parameter 159 updated: new FOC controlled mode. - Axis parameter 212 (actual controlled angle) new.
2.03	2013-SEP-03	JP	Removed Parameters 238,239,240, updated revision history.
2.04	2016-FEB-16	ED	Added Block-Hall to Axis parameter 159. Updated GIO command table.
2.05	2018-FEB-08	ED	Revision history updated for FW 2.09. Removed first steps with old TMCL-IDE.
2.06	2020-JAN-31	ED	Axis parameter 255 (enable driver) added.

12 References

[TMCM-1640] TMCM-1640 Hardware Manual
[TMCL-IDE] TMCL-IDE User Manual
[TMC603] TMC603 Datasheet
[QBL4208] QBL4208 Manual
Please refer to our homepage http://www.trinamic.com.