Przemysłowe Sieci Komputerowe

Komunikacja z serwonapędem
Sterownik silnika BLDC Nanotec C5-E
Standardy DS402 / DS301

Paweł Strączyński

p.straczynski@tu.kielce.pl

Katedra Urządzeń Elektrycznych i Automatyki

Politechnika Świętokrzyska

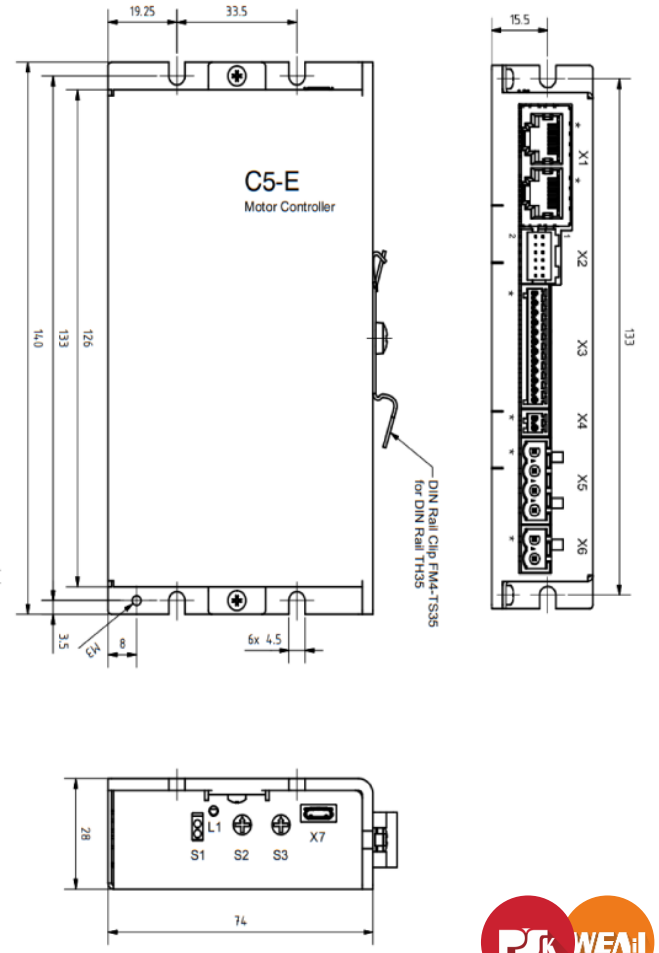
Kontrolery silnika BLDC Nanotec serii C5-E

VERSIONS

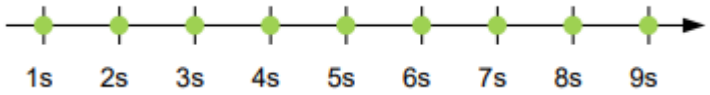
Type	Interface	Rated Current (RMS) A	Peak Current (RMS) A	Operating Voltage VDC	Encoder Input	Brake Output	Corresponding Motors	Weight kg
C5-E-1-03	USB, Modbus RTU, IO (clock direction; analog)	6	6	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-2-03	USB, Modbus RTU, IO (clock direction; analog)	10	30	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-1-09	USB, CANopen, IO (clock direction; analog)	6	6	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-2-09	CANopen, USB, IO (clock direction; analog)	10	30	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-1-11	EtherNet/IP, USB, IO (clock direction; analog)	6	6	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-2-11	USB, EtherNet/IP, IO (clock direction; analog)	10	30	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-1-21	USB, EtherCAT, IO (clock direction; analog)	6	6	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-2-21	EtherCAT, USB, IO (clock direction; analog)	10	30	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-1-81	USB, Modbus TCP, IO (clock direction; analog)	6	6	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27
C5-E-2-81	USB, Modbus TCP, IO (clock direction; analog)	10	30	12 - 48	✓	✓	Stepper Motors, Brushless DC motors	0.27

Kontrolery silnika BLDC Nanotec serii C5-E

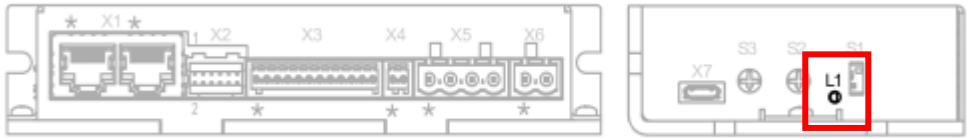
Property	Description / value
Operating voltage	12 V DC to 48 V DC +/-5%
Rated current	C5-E-1-03 (*low current*): 6 A_{rms} C5-E-2-03 (*high current*): 10 A_{rms}
Peak current	C5-E-1-03 (*low current*): 6 A_{rms} C5-E-2-03 (*high current*): 30 A_{rms} for 5 seconds
Commutation	Stepper motor – open loop, stepper motor – closed loop with encoder, BLDC motor – closed loop with Hall sensor, and BLDC motor – closed loop with encoder
Operating modes	*Profile Position Mode*, *Profile Velocity Mode*, *Profile Torque Mode*, *Velocity Mode*, *Homing Mode*, *Interpolated Position Mode*, *Cyclic Sync Position Mode*, *Cyclic Sync Velocity Mode*, *Cyclic Synchronous Torque Mode*, *Clock-Direction Mode*
Set value setting / programming	*Clock-direction*, *analog*, *NanoJ program*
Interfaces	USB, RS-485 electrically isolated (Modbus RTU)
Inputs	■ 5 inputs, 24 V (inputs 1 to 5) individually switchable between 5 and 24 V, factory setting: 5 V ■ 1 analog input, 10 bit, switchable 0-10 V or 0-20 mA, factory setting: 0-10 V ■ 1 analog input, 10 bit, 0-10 V
Outputs	3 outputs, (open drain, 0 switching, max. 24 V and 100 mA)
Protection circuit	Overvoltage and undervoltage protection Overtemperature protection (> 75° Celsius on the power board) Polarity reversal protection: In the event of a polarity reversal, a short-circuit will occur between supply voltage and GND over a power diode; a line protection device (fuse) is therefore necessary in the supply line. The values of the fuse are dependent on the application and must be dimensioned ■ greater than the maximum current consumption of the controller, ■ less than the maximum current of the voltage supply. If the fuse value is very close to the maximum current consumption of the controller, a medium / slow tripping characteristics should be used.



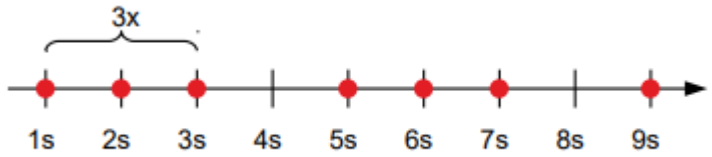
Sygnalizacja błędów kontrolera



Normalna praca



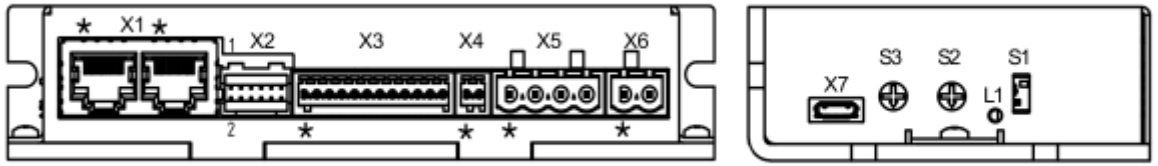
Sygnalizacja LED



Błąd

Flash rate	Error
1	General
2	Voltage
3	Temperature
4	Overcurrent
5	Controller
6	Watchdog-Reset

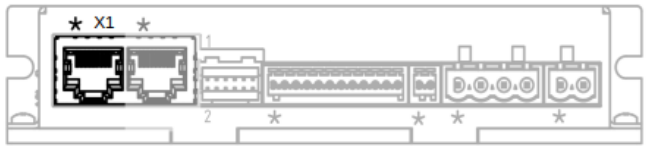
Podłączenie sterownika



Connection	Function
X1	Modbus RTU IN and OUT
X2	Encoder and Hall sensor connection
X3	Digital/analog inputs and outputs
X4	Brake connection
X5	Motor connection
X6	Voltage supply
X7	Micro USB connection
S1	150 ohm termination resistor (switch set to ON)
S2	Hex coding switch for slave address and baud rate, 16s place (e.g., $\mathbf{F}0_h$)
S3	Hex coding switch for slave address and baud rate, 1s place (e.g., $0\mathbf{F}_h$)
L1	Power LED

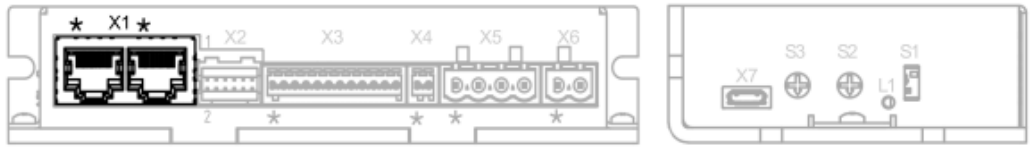
Podłączenie – interfejs komunikacyjny Modbus

Modbus TCP (Ethernet)



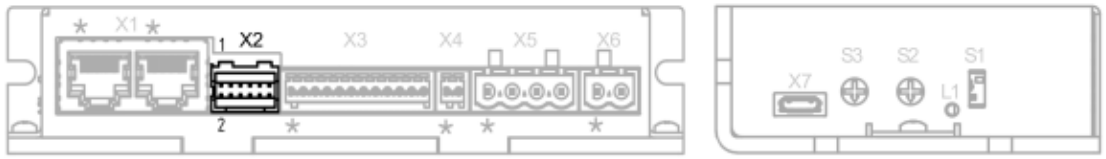
Pin	Function	Note
1	Tx+	
2	Tx-	
3	Rx+	
4	n.c.	
5	n.c.	
6	Rx-	
7	n.c.	
8	n.c.	

Modbus RTU (RS-485)



Pin	Function	Note
1	n.c.	
2	n.c.	
3	n.c.	
4	RS-485+	
5	RS-485-	
6	n.c.	
7	n.c.	Pin 7 of the two connectors internally connected to one another
8	COMMON	Pin 8 of the two connectors connected to one another

Podłączenie enkodera i czujników Halla



Pin	Function	Note
1	GND	
2	Vcc	5 V DC, output and supply voltage for encoder / Hall sensor; max. 200 mA
3	A	5 V signal, max. 1 MHz
4	B	5 V signal, max. 1 MHz
5	A\	5 V signal, max. 1 MHz
6	B\	5 V signal, max. 1 MHz
7	I	5 V signal, max. 1 MHz
8	I\	5 V signal, max. 1 MHz
9	Hall 1	5 V signal

Jeśli używany jest enkoder single-ended, kanały A/, B/ i I/ nie są analizowane!

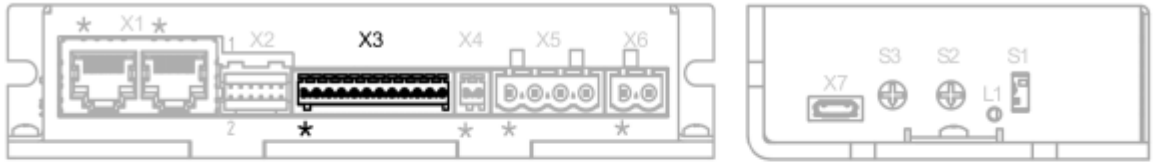
Aby upewnić się, że enkoder single-ended jest poprawnie wykrywany:

- Ustaw obiekt 2059h na wartość „2”.
- Nie podłączaj niczego do pinów A\, B\, I\ i nie podłączaj tych pinów do masy (GND).

Pin	Function	Note
10	Hall 2	5 V signal
11	Hall 3	5 V signal
12	Shielding	Shielding

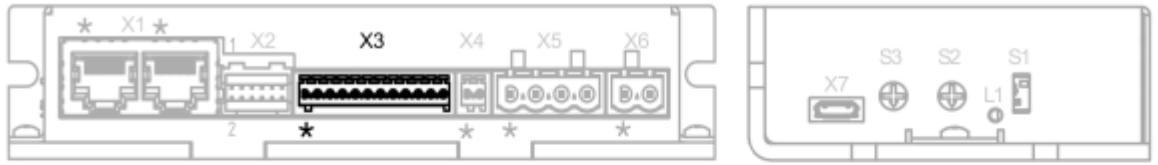
Type	Switching thresholds	
	On	Off
Single	> 3.8 V	< 0.26 V
Difference	> 3.8 V	< 0.26 V

Podłączenie IO



Pin	Function	Note
1	+10 V DC	Output voltage, max. 200 mA
2	Digital input 1	5 V / 24 V signal, switchable by means of software with object 3240_h, max. 1 MHz; clock input in clock-direction mode
3	Digital input 2	5 V / 24 V signal, switchable by means of software with object 3240_h, max. 1 MHz; direction input in clock-direction mode
4	Digital input 3	5 V / 24 V signal, switchable by means of software with object 3240_h
5	Digital input 4	5 V / 24 V signal, switchable by means of software with object 3240_h
6	Digital input 5	5 V / 24 V signal, switchable by means of software with object 3240_h
7	Analog input 1	10 bit, 0-10 V or 0-20 mA, switchable by means of software with object 3221_h
8	Analog input 2	10 bit, 0-10 V, not switchable by means of software
9	Digital output 1	Open drain, maximum 24 V / 100 mA
10	Digital output 2	Open drain, maximum 24 V / 100 mA
11	Digital output 3	Open drain, maximum 24 V / 100 mA
12	GND	

Podłączenie IO



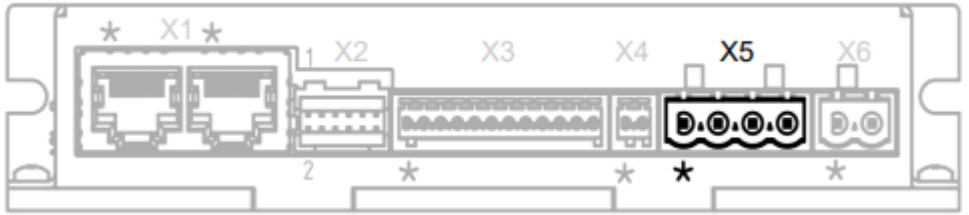
Max. Voltage	Switching thresholds	
	On	Off
5 V	> 3.8 V	< 0.26 V
24 V	> 14.42 V	< 4.16 V

Configuration of analog input	Input resistance (maximum value)
Voltage input	approx. 147 kOhm
Current input (analog input 1 only)	at 1 mA: approx. 350 ohm
Current input (analog input 1 only)	at 20 mA: approx. 283 ohm

Connection data	min	max
Conductor cross section, rigid, min.	0.14 mm^2	0.5 mm^2
Conductor cross section, flexible, min.	0.14 mm^2	0.5 mm^2
Conductor cross section, flexible, min. Wire-end sleeve without plastic sleeve, min.	0.25 mm^2	0.5 mm^2
Conductor cross section, min. AWG	26	20
Min. AWG acc. to UL/CUL	28	20

Pin	Function	Note
1	+10 V DC	Output voltage, max. 200 mA
2	Digital input 1	5 V / 24 V signal, switchable by means of software with object 3240_h, max. 1 MHz; clock input in clock-direction mode
3	Digital input 2	5 V / 24 V signal, switchable by means of software with object 3240_h, max. 1 MHz; direction input in clock-direction mode
4	Digital input 3	5 V / 24 V signal, switchable by means of software with object 3240_h
5	Digital input 4	5 V / 24 V signal, switchable by means of software with object 3240_h
6	Digital input 5	5 V / 24 V signal, switchable by means of software with object 3240_h
7	Analog input 1	10 bit, 0-10 V or 0-20 mA, switchable by means of software with object 3221_h
8	Analog input 2	10 bit, 0-10 V, not switchable by means of software
9	Digital output 1	Open drain, maximum 24 V / 100 mA
10	Digital output 2	Open drain, maximum 24 V / 100 mA
11	Digital output 3	Open drain, maximum 24 V / 100 mA
12	GND	

Podłączenie silnika BLDC / krokowego



Pin	Function (Stepper)	Function (BLDC)
1	A	U
2	A\	V
3	B	W
4	B\	Not used

Connection data	min	max
Conductor cross section, rigid, min.	0.2 mm^2	1.5 mm^2
Conductor cross section, flexible, min.	0.2 mm^2	1.5 mm^2
Conductor cross section, flexible, min. Wire-end sleeve without plastic sleeve, min.	0.25 mm^2	1.5 mm^2
Conductor cross section, flexible, min. Wire-end sleeve min. Plastic sleeve min.	0.25 mm^2	0.75 mm^2
Conductor cross section, min. AWG	24	16
Min. AWG acc. to UL/CUL	24	16

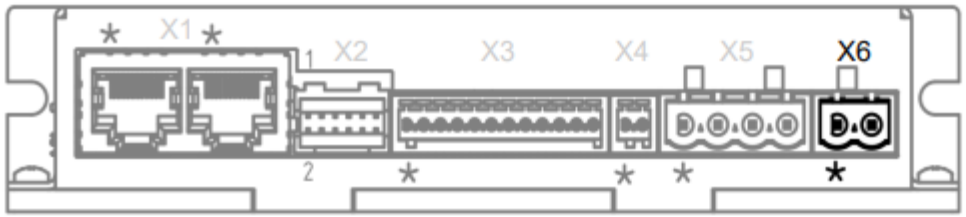
Podłączenie zasilania

Maksymalne napięcie zasilania to 50.4V!

Jeśli napięcie zasilania będzie za wysokie kontroler odłączy napięcie od silnika i wyświetli błąd w rejestrze 2034h

Minimalne napięcie robocze to 11.4V

Aby uniknąć przekroczenia dopuszczalnego napięcia roboczego ro zasilania należy podłączyć równolegle kondensator 4700uF/50V



Pin	Function	Note
1	+UB	12 V - 48 V DC, ±5%
2	GND	

Connection data	min	max
Conductor cross section, rigid, min.	0.2 mm^2	1.5 mm^2
Conductor cross section, flexible, min.	0.2 mm^2	1.5 mm^2
Conductor cross section, flexible, min. Wire-end sleeve without plastic sleeve, min.	0.25 mm^2	1.5 mm^2
Conductor cross section, flexible, min. Wire-end sleeve min. Plastic sleeve min.	0.25 mm^2	0.75 mm^2
Conductor cross section, min. AWG	24	16
Min. AWG acc. to UL/CUL	24	16

Podłączenie przez USB

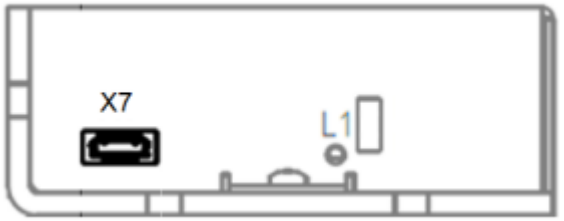
Po podłączeniu kontrolera do komputera za pomocą przewodu USB jest on wykrywany jako pamięć masowa.

Dostępne są trzy pliki:
- plik konfiguracyjny (cfg.txt),
- program NanoJ (vmmcode.usr),
- plik informacyjny (info.txt), w którym można znaleźć numery seryjne i wersję oprogramowania sprzętowego produktu.

W ten sposób można zapisać plik konfiguracyjny lub program NanoJ na kontrolerze.

Wszystkie inne pliki zostaną skasowane po odłączeniu zasilania.

Podczas komunikacji przez USB należy również zasilić urządzenie.



Struktura pliku konfiguracyjnego

```
; This is a comment line
```

Komentarz

```
<Index>:<Subindex>=<Value>
```

Zapis parametru

Wartości index i subindex podajemy heksadecymalnie.

Aby zapisać parametr jako liczbę heksadecymalną należy poprzedzić ją przedrostkiem 0x

Przykładowy plik konfiguracyjny

```
3202:00.03=1  ;Ustaw bit 3 w rejestrze 3202:00h
3202:00.04=0  ;Resetuj bit 4 w rejestrze 3202:00h
3202:00|=0x08 ;Bitowa operacja OR
3202:00&=0x08 ;Bitowa operacja AND
```

Niedozwolone jest pozostawianie białych znaków z lewej oraz prawej strony!

Przykład błędnych komend:

```
3202:00.03 =1 ;Błędny zapis!
3202:00.03 = 1 ;Błędny zapis!
3202:00.03= 1  ;Błędny zapis!
```

Konfiguracja adresu IP

Kontroler potrzebuje prawidłowego adresu IP. Adres IP można uzyskać w jeden z następujących sposobów:

- DHCP: serwer DHCP przypisuje adres IP do kontrolera (ustawienie domyślne).
- AutoIP: Kontroler automatycznie określa odpowiedni adres IP. Warunkiem jest tutaj, aby partnerzy komunikacyjni znajdują się w tej samej fizycznej podsieci i również korzystają z funkcji AutoIP.
- Statyczny adres IP: jest definiowany przez użytkownika.

Konfiguracja statycznego adresu IP

Index	Description
2010_h	IP configuration, bit mask with the following meaning: Bit 0: A static IP address from object 2011_h and the network mask from object 2012_h are used.
2011_h	Static IP address, 4 bytes in hex coding
2012_h	Static IP subnet mask, 4 bytes in hex coding
2013_h	Gateway address
2014_h	Active IP address, 4 bytes in hex coding
2015_h	Active IP subnet mask, 4 bytes in hex coding
2016_h	Currently used gateway address
$200F_h$	MAC address

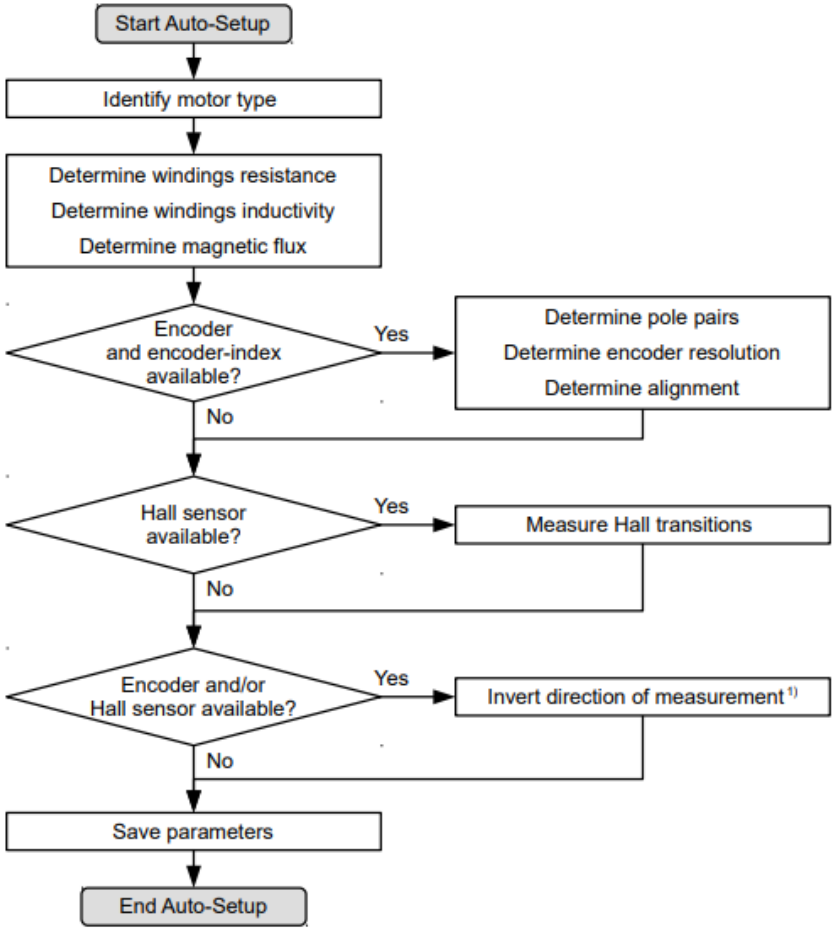
Konfiguracja napędu – wymagane parametry

Parameter	All motors independent of the configuration
Motor type (stepper motor or BLDC motor)	✓
Winding resistance	✓
Winding inductance	✓
Interlinking flux	✓

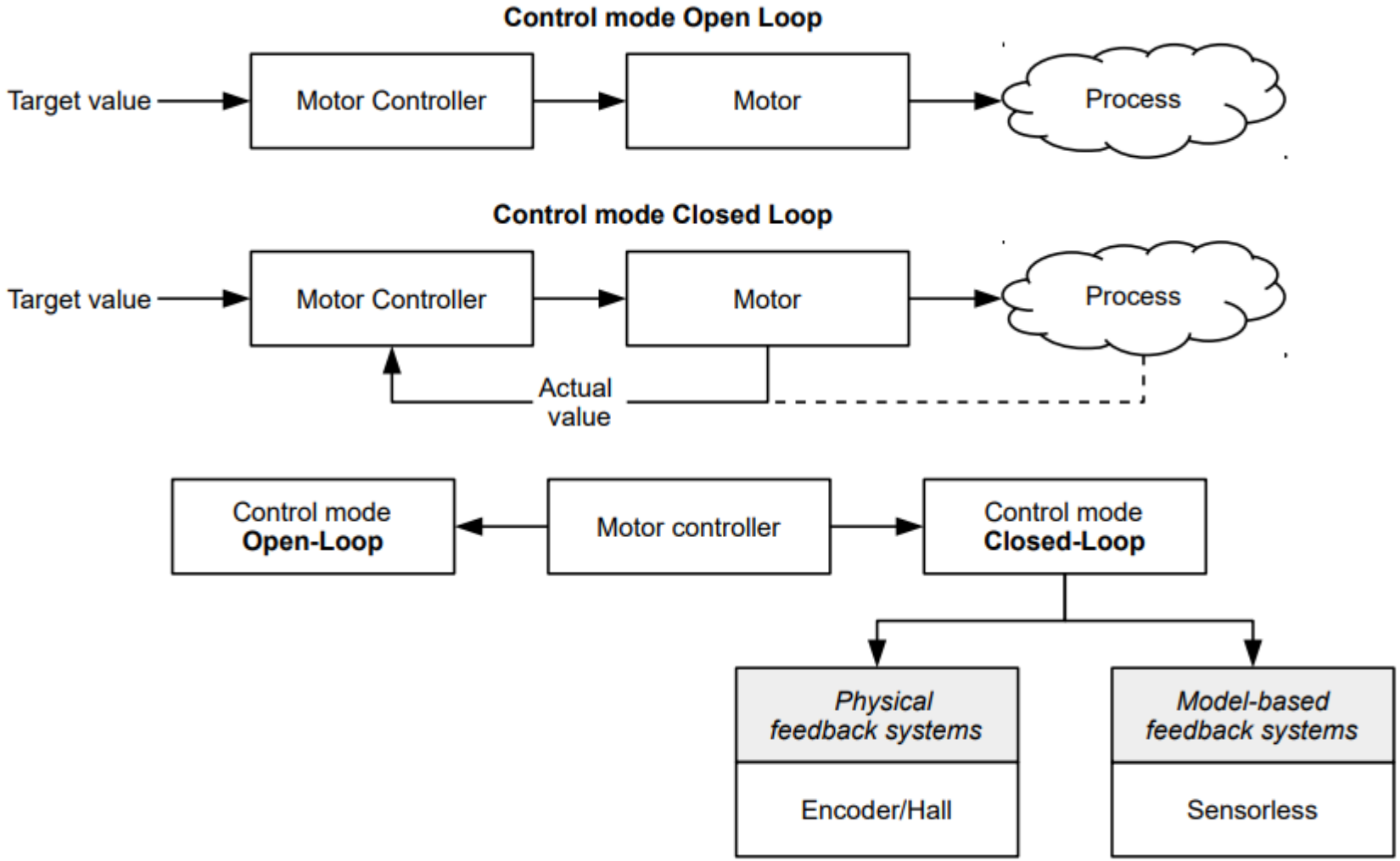
Parameter	Motor without encoder	Motor with encoder and index	Motor with encoder without index
Encoder resolution	-	✓	---
Alignment (shifting of the electrical zero to the index)	-	✓	---

Parameter	Motor without Hall sensor	Motor with Hall sensor
Hall transitions	-	✓

Konfiguracja napędu – wymagane parametry



Tryby sterowania



Tryby sterowania

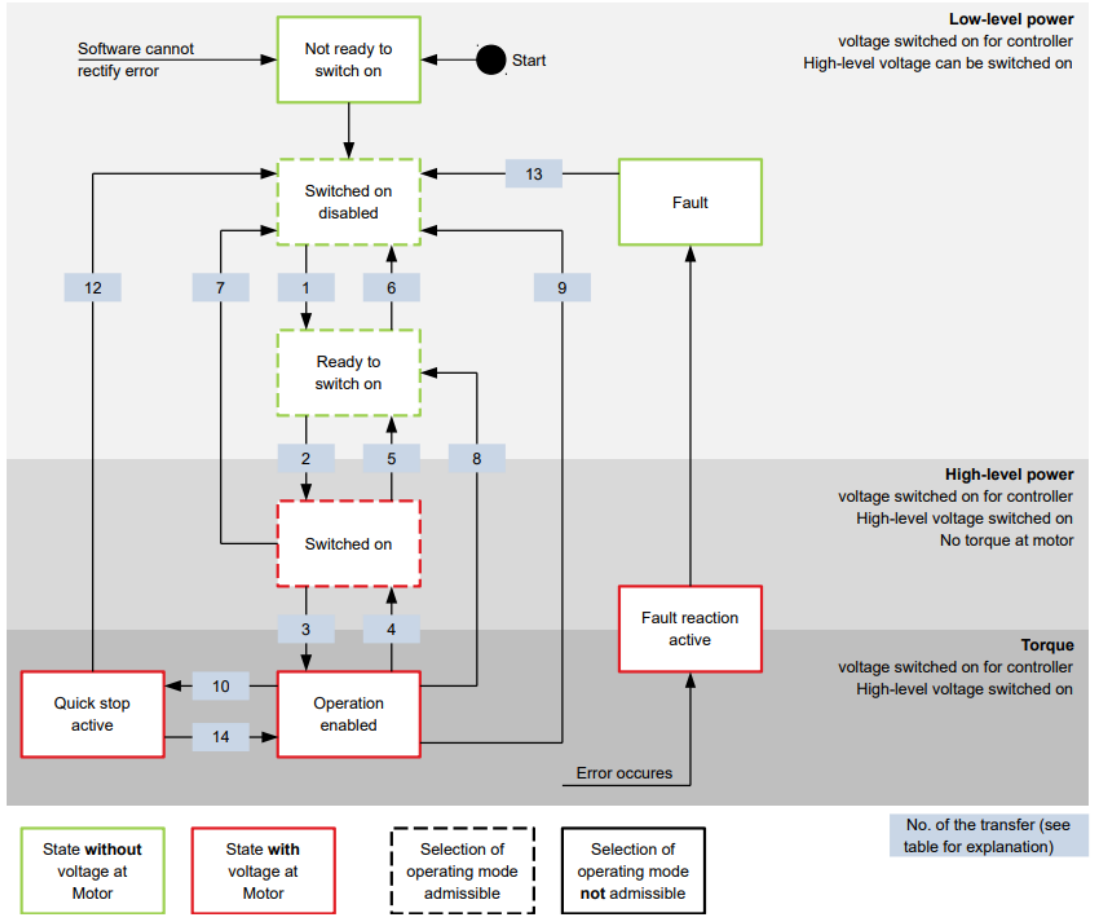
Control mode	Stepper motor	BLDC motor
Open Loop	yes	no
Closed Loop	yes	yes

Feedback	Stepper motor	BLDC motor
Hall	no	yes
Encoder	yes	yes
Sensorless	yes	yes

Operating mode	Control mode	
	Open Loop	Closed Loop
Profile Position	yes	yes
Velocity	yes	yes
Profile Velocity	yes	yes
Profile Torque	no[1)]	yes
Homing	yes[2)]	yes
Interpolated Position Mode	yes[3)]	yes
Cyclic Synchronous Position	yes[3)]	yes
Cyclic Synchronous Velocity	yes[3)]	yes
Cyclic Synchronous Torque	no[1)]	yes
Clock-direction	yes	yes

Standard CiA 402 – maszyna stanów

Aby przełączyć kontroler w stan gotowości konieczne jest przejście przez automat stanów CiA 402



Standard CiA 402 – maszyna stanów

Zmiany stanu są wymagane w obiekcie 6040h (Control Word)

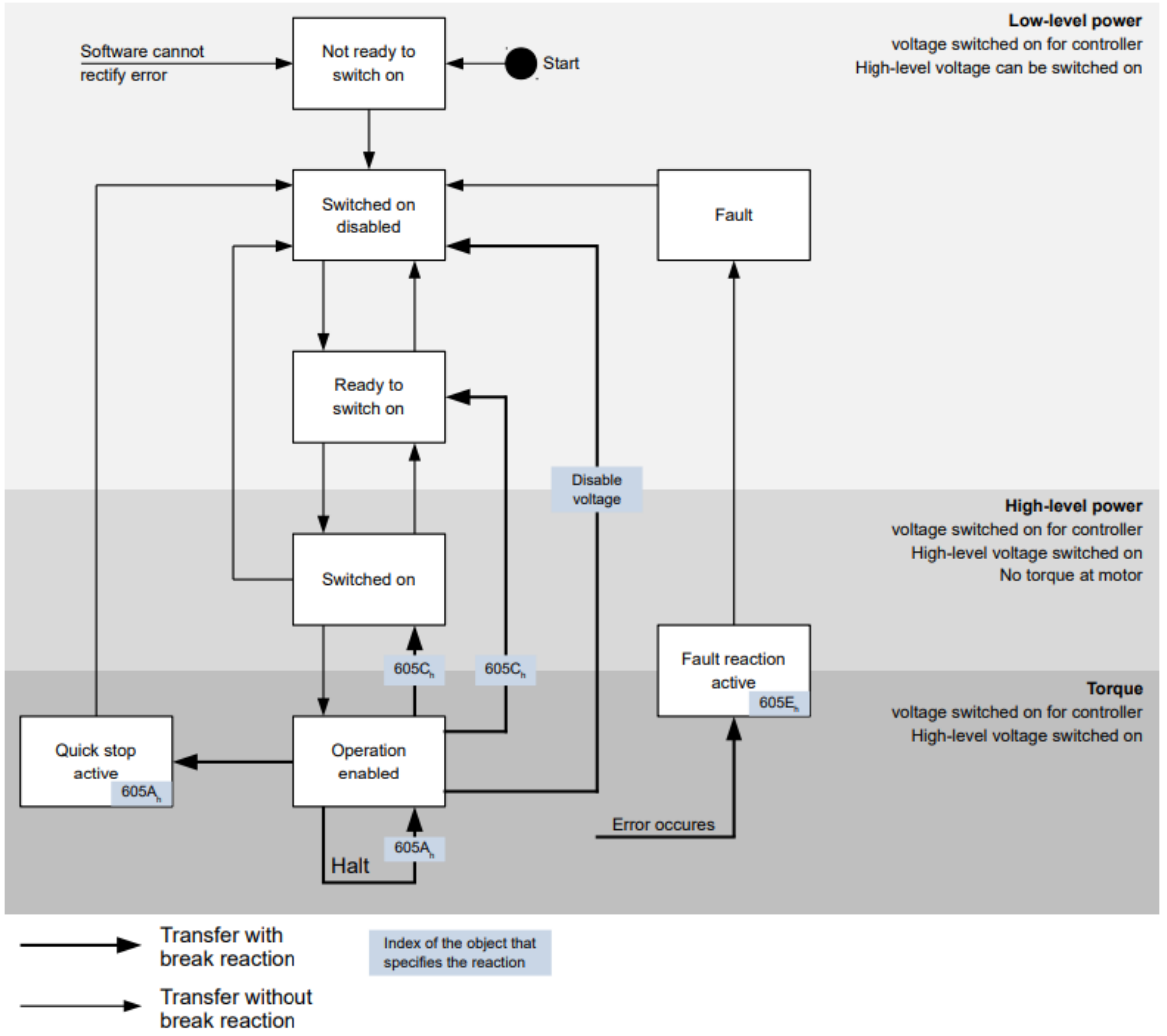
Command	Bit in object 6040_h					Transition
	Bit 7	Bit 3	Bit 2	Bit 1	Bit 0	
Shutdown	0	X	1	1	0	1, 5, 8
Switch on	0	0	1	1	1	2
Disable voltage	0	X	X	0	X	6, 7, 9, 12
Quick stop	0	X	0	1	X	10
Disable operation	0	0	1	1	1	4
Enable operation	0	1	1	1	1	3
Enable operation after quick stop (if **$605A_h$** is 5 or 6)	0	1	1	1	1	14
Fault reset	↑	X	X	X	X	13

Standard CiA 402 – maszyna stanów

Aktualny stan automatu można znaleźć w obiekcie 6041h (Status Word)

Statusword (6041_h)	State
xxxx xxxx x0xx 0000	Not ready to switch on
xxxx xxxx x1xx 0000	Switch on disabled
xxxx xxxx x01x 0001	Ready to switch on
xxxx xxxx x01x 0011	Switched on
xxxx xxxx x01x 0111	Operation enabled
xxxx xxxx x00x 0111	Quick stop active
xxxx xxxx x0xx 1111	Fault reaction active
xxxx xxxx x0xx 1000	Fault

Standard CiA 402 – maszyna stanów



Tryb CSP (Cyclic Synchronus Postion) – 0x08

Aby aktywować tryb CSP należy do rejestru 6060h (Modes Of Operation) wysłać wartość 8

Funkcje specjalne Status Word w trybie CSP

Bit	Value	Description
8	0	The controller is not in sync with the fieldbus
8	1	The controller is in sync with the fieldbus
10	0	Reserved
10	1	Reserved
12	0	Controller does not follow the target; the preset of **607A**$_h$ (Target Position) is ignored
12	1	Controller follows the target; object **607A**$_h$ (Target Position) is used as the input for position control.
13	0	No following error
13	1	Following error

Tryb CSP (Cyclic Synchronus Postion) – 0x08

Rejestry kontrolujące prace w trybie CSP

$607A_h$ (Target Position): This object must be written cyclically with the position set value.

$607B_h$ (Position Range Limit): This object contains the preset for an overrun or underrun of the position specification.

$607D_h$ (Software Position Limit): This object defines the limitations within which the position specification ($607A_h$) must be located.

6065_h (Following Error Window): This object specifies a tolerance corridor in both the positive and negative direction from the set specification. If the actual position is outside of this corridor for longer than the specified time (**6066_h**), a following error is reported.

6066_h (Following Error Time Out): This object specifies the time range in milliseconds. If the actual position is outside of the position corridor (**6065_h**) for longer than this time range, a following error is triggered.

6085_h (Quick-Stop Deceleration): This object contains the braking deceleration for the case that a quick-stop is triggered.

$605A_h$ (Quick-Stop Option Code): This object contains the option that is to be executed in the event of a quick-stop.

6080_h (Max Motor Speed): Maximum speed

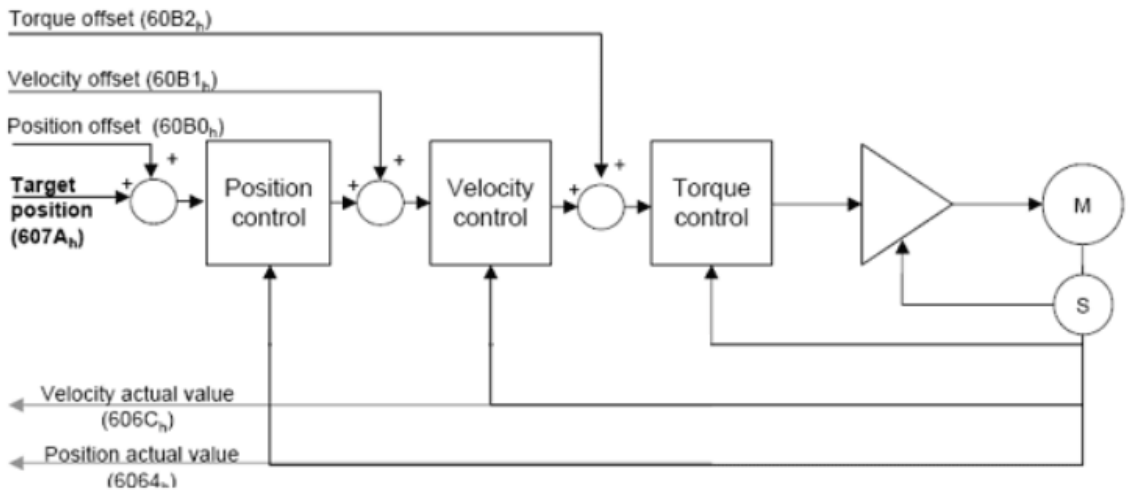
$60C2_h$:01_h (Interpolation Time Period): This object specifies the time of a *cycle*; a new set value must be written in **$607A_h$** in these time intervals.
The following applies here: cycle time = value of **$60C2_h$**:01_h * $10^{\text{value of 60C2:02}}$ seconds.

$60C2_h$:02_h (Interpolation Time Index): This object specifies the time basis of the cycles. Currently, only value **$60C2_h$**:02_h=-3 is supported; this yields a time basis of 1 millisecond.

Tryb CSP (Cyclic Synchronus Postion) – 0x08

Rejestry z informacją zwrotną z pracy w trybie CSP

6064_h (Position Actual Value)
$606C_h$ (Velocity Actual Value)
$60F4_h$ (Following Error Actual Value)



Tryb Profile Position – 0x01

Aby aktywować tryb PP należy do rejestru 6060h (Modes Of Operation) wysłać wartość 1

Funkcje specjalne Control Word w trybie PP

Bit 4 starts a travel command. This is carried out on a transition from "0" to "1". An exception occurs if changing from another operating mode to *Profile Position*: If bit 4 is already set, it does not need to be set to "0" and then back to "1" in order to start the travel command.
Bit 5: If this bit is set to "1", a travel command triggered by bit 4 is immediately executed. If it is set to "0", the just executed travel command is completed and only then is the next travel command started.
Bit 6: With "0", the target position (**607A**$_h$) is absolute and with "1" the target position is relative. The reference position is dependent on bits 0 and 1 of object **60F2**$_h$.
Bit 8 (Halt): If this bit is set to "1", the motor stops. On a transition from "1" to "0", the motor accelerates with the set start ramp to the target speed. On a transition from "0" to "1", the motor brakes and comes to a standstill. The braking deceleration is dependent here on the setting of the "Halt Option Code" in object **605D**$_h$.
Bit 9 (Change on setpoint): If this bit is set, the speed is not changed until the first target position is reached. This means that, before the first target is reached, no braking is performed, as the motor should not come to a standstill at this position.

Bit 9 w Control Word jest ignorowany, jeśli prędkość rampy nie jest osiągnięta w punkcie docelowym.

Tryb Profile Position – 0x01

Aby aktywować tryb PP należy do rejestru 6060h (Modes Of Operation) wysłać wartość 1

Funkcje specjalne Control Word w trybie PP

Bit 10 (Target Reached): This bit is set to "1" if the last target was reached and the motor remains within a tolerance window (**6067**$_h$) for a preset time (**6068**$_h$).
Bit 11: Limit exceeded: The demand position is above or below the limit values set in **607D**$_h$.
Bit 12 (Set-point acknowledge): This bit confirms receipt of a new and valid set point. It is set and reset in sync with the "New set-point" bit in the controlword.
There is an exception in the event that a new movement is started before another one has completed and the next movement is not to occur until after the first one has finished. In this case, the bit is reset if the command was accepted and the controller is ready to execute new travel commands. If a new travel command is sent even though this bit is still set, the newest travel command is ignored.
The bit is not set if one of the following conditions is met:

- The new target position can no longer be reached while adhering to all boundary conditions.
- A target position was already traveled to and a target position was already specified. A new target position can only be specified after the current positioning has been concluded.

Bit 13 (Following Error): This bit is set in *closed loop* mode if the following error is greater than the set limits (**6065**$_h$ (Following Error Window) and **6066**$_h$ (Following Error Time Out)).

Tryb Profile Position – 0x01

Polecenie ruchu

- W obiekcie 607Ah (Target position) nowa pozycja docelowa jest określona w jednostkach użytkownika
- Polecenie jazdy jest następnie wyzwalane przez ustawienie bitu 4 w obiekcie 6040h (Control word). Jeśli pozycja docelowa jest prawidłowa, sterownik odpowiada bitem 12 w obiekcie 6041h (Status word) i rozpoczyna pozycjonowanie ruchu.
- Po osiągnięciu pozycji bit 10 w słowie statusowym jest ustawiany na stan wysoki (1)