Using BASIC Scripts of a FAULHABER Motion Controller V3.0

Summary

This Application Note is a comprehensive introduction into automation of FAULHABER Motion Controller V3.0 using its local scripting capabilities.

As these scripts usually will have to deal with enabling and disabling the drive as well as changing the Mode of Operation (OpMode) the Application Note starts with a compact introduction into the typical interaction with the control part of such a servo-drive (see chapter How to interact with the MC drive function).

Chapter The FAULHABER MC BASIC explains the capabilities and limitations of the local BASIC scripting engine.

Some suggestions on how to create a program structure and some useful coding patterns are collected in chapter Patterns for embedded scripts followed by two heavily commented examples.

Some more advanced patterns are introduced in chapter Additional Patterns.

Applies To

All FAULHABER Motion Controller V 3.0:

MC 5004

MC 5005

MC 5010

MCS

Related FAULHABER Documents

Document	Description
Programming Manual	Description of the BASIC based programming environment of the FAULHABER Motion Controller V3.0
Quick start description	Description of the first steps for commissioning and operation of FAULHABER Motion Controllers
Drive functions	Description of the operating modes and functions of the drive
Motion Manager 6	Instruction Manual for FAULHABER Motion Manager PC software

How to interact with the MC drive function

Before we start coding we need to understand the basic concept of how to interact with the drive function of the FAULHABER Motion Controller (MC).

The purpose of the MC is to control the movement of a single motor in a closed loop. Additional sensors might be connected to the MC to limit the movement or to reset the motor position to 0 at a defined position during one of the homing sequences.

Each of the OpModes can be adjusted to the application by setting a bunch of parameters. But that's static of course. One of the reasons to use a local script might be to either change these parameters during operation or to switch between different OpModes.

Typically changing of parameters can be done by a master controller connected to the MC via one of the communication interfaces. However if there is no master controller at all or if some of the changes shall be executed partly autonomously it might be an advantage to use local scripting at the Motion Controller directly.

Examples could be:

- Executing a homing sequence after each power up and then switching to position control with an analog reference value (**A**nalog **P**osition **C**ontrol).
- Implementing a discrete brake/enable interface for a controller in stand-alone mode.
- Changing to a predefined different set of parameters during a load cycle, even if connected to a master but without having to access all the parameters from the master PLC.
- Using analog inputs to change limits of the feedback control such as maximum speed or torque limits.
- Create a predefined complex motion profile by subsequently changing profile parameters and control limits while executing the movement.

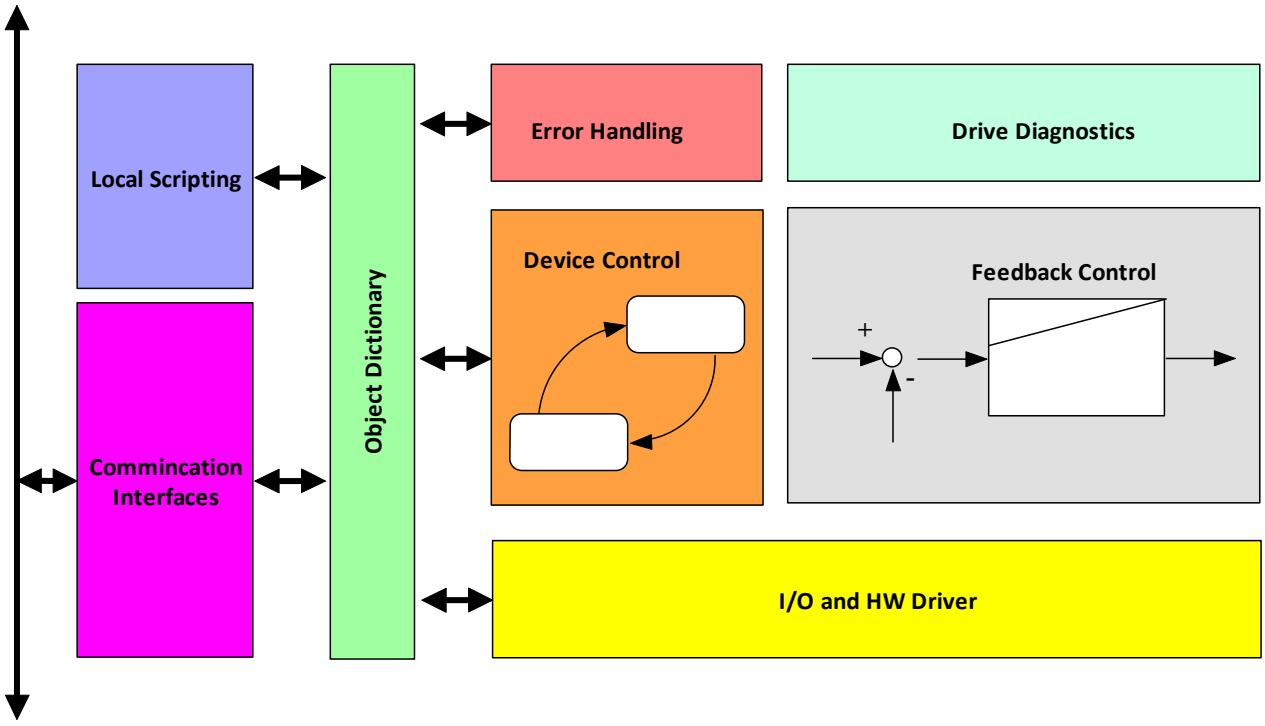


Figure 1 Main Parts of the MC internal firmware

Accessing MC parameters

The FAULHABER Motion Controller V3.0 is a servo-drive compatible to the CiA 402 / IEC 61800-7-200 standard used in CANopen and EtherCAT environments. All of the parameters, references, control inputs and actual values of the drive are collected in the Object Dictionary (OD).

Any access to the application is routed via one of the parameters collected in the OD. Consequently the parameters are referred as objects. The basic operation here is a read- and/or write-access to the parameters collected here – read object and write object[1]. So basically to interact with such a drive will result in a sequence of read and write commands such as:

- Set Target Velocity to xxxx
- Read Actual Velocity
- …

[1] CANopen and EtherCAT additionally provide optimized access to a predefined set of parameters for real-time data exchange by so called Process Data Objects (PDO), which define a set of parameters cyclically exchanged during real-time operation.

All parameters/objects are identified by a 16 bit index – the parameter number and an 8 bit sub-index, allowing for structured parameters.

Simple Parameter

Idx	Sub	Parameter
0x607A	00	Target Position

Idx	Sub	Parameter
0x60FF	00	Target Velocity

Structured Parameter

Idx	Sub	Parameter
0x2311	00	Digital I/Os
	01	Logical Input State
	02	Physical Input State
	03	Output State

Table 1

Within BASIC scripts for the Motion Controller V3.0 the commands to access the parameters are:

SETOBJ <index>.<Sub> = <value> e.g.: **SETOBJ $607A.$00 = 10000**

a = GETOBJ <index>.<Sub> e.g.: **a = GETOBJ $2311.$01**

Parameter index and sub-index are usually denoted as hexadecimal numbers. The $ sign is used to denote a hexadecimal number within the BASIC environment.

If you don't want to memorize all the parameter numbers, there is an include file which assigns symbolic names to the most frequently used parameters.
The file "`MotionParameters.bi`" is included by default in new script files.

Main units within the MC drive

To easily use the drive, a general idea about the different functional parts within the Motion Controller might be useful (Figure 1).

Device Control

Enables or disables the motor control. Parameters are the controlword **0x6040.00** and the statusword **0x6041.00** of the servo-drive.

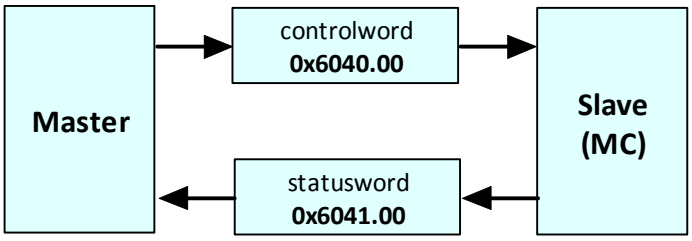


Figure 2 Interaction between master controller and servo-drive

Selection of the OpMode (see Table 4) using the parameter Modes of operation (**0x6060.00**).

Feedback Control

The motor control unit controls the torque-, velocity – or position of a motor in a closed loop. The feedback-control will try to follow the target values of the selected OpMode. Actual values are calculated. Parameters are:

Loop	Target Values	Actual Values	Default-Scaling
Position[1)]	0x607A.00	0x6064.00	Motor Encoder increments
Velocity[1)]	0x60FF.00	0x606C.00	min^{-1}
Torque	0x6071.00	0x6077.00	nominal torque / 1000
Voltage	0x2341.00	0x2340.xx[2)]	10mV / LSB

[1)] position and velocity scaling can be changed by using the factor group

[2)] sub-index depending on the type of motor – DC or BL

Additional parameters are:

- Torque limits
- Limits for acceleration and deceleration
- Limits for the motor speed or the profile speed
- Position limits

Drive Diagnostics

Supervises the controlled motion and updates the thermal models. Drive Diagnostics will check for any limits being reached (Software Position Limits or limit switches) and will check whether the target position or the target speed are reached. The results are concentrated in the device status word 0x2324.01. Additional information is available via the supply voltages or the calculated internal temperatures.

Error Reaction

Conditions that are considered to be an error are collected in the FAULHABER error word 0x2320.00. Different automatic reactions to the different errors can be configured using the error masks in 0x2321.xx. If connected to the system via one of the communication systems additional EMCY messages will inform the master about the detected errors. This however does not apply to the local scripts. They don't receive error messages but can react to any combination of flags in the device status word.

I/O and HW-drivers

This unit is responsible for the update of the discrete interfaces. The type of interfaces connected to the drive is parameterizable and actual values can be read or written in the case of digital outputs. Analog inputs can be pre-scaled before being used by the feedback control without any scripting involved. In addi-

tion to these built in features, scripts could read analog inputs and use its actual values to manipulate parameters of the feedback control, e.g. limits for speed or torque.

Interaction with the drive state machine

Servo-drives according to CiA 402 need to be enabled or disabled stepping through the drive state machine in Figure 5.

Auto-enable the control and power-stage

The drive state machine is a powerful means to change the drive state from disabled to enabled or to change to a quick stop with defined reaction independently from the selected OpMode. However most stand-alone applications won't need or use this functionality. So if, for instance, the application requires analog position control, a script could be used to add an initial homing sequence but other than an initial start no interaction with the state machine is involved.

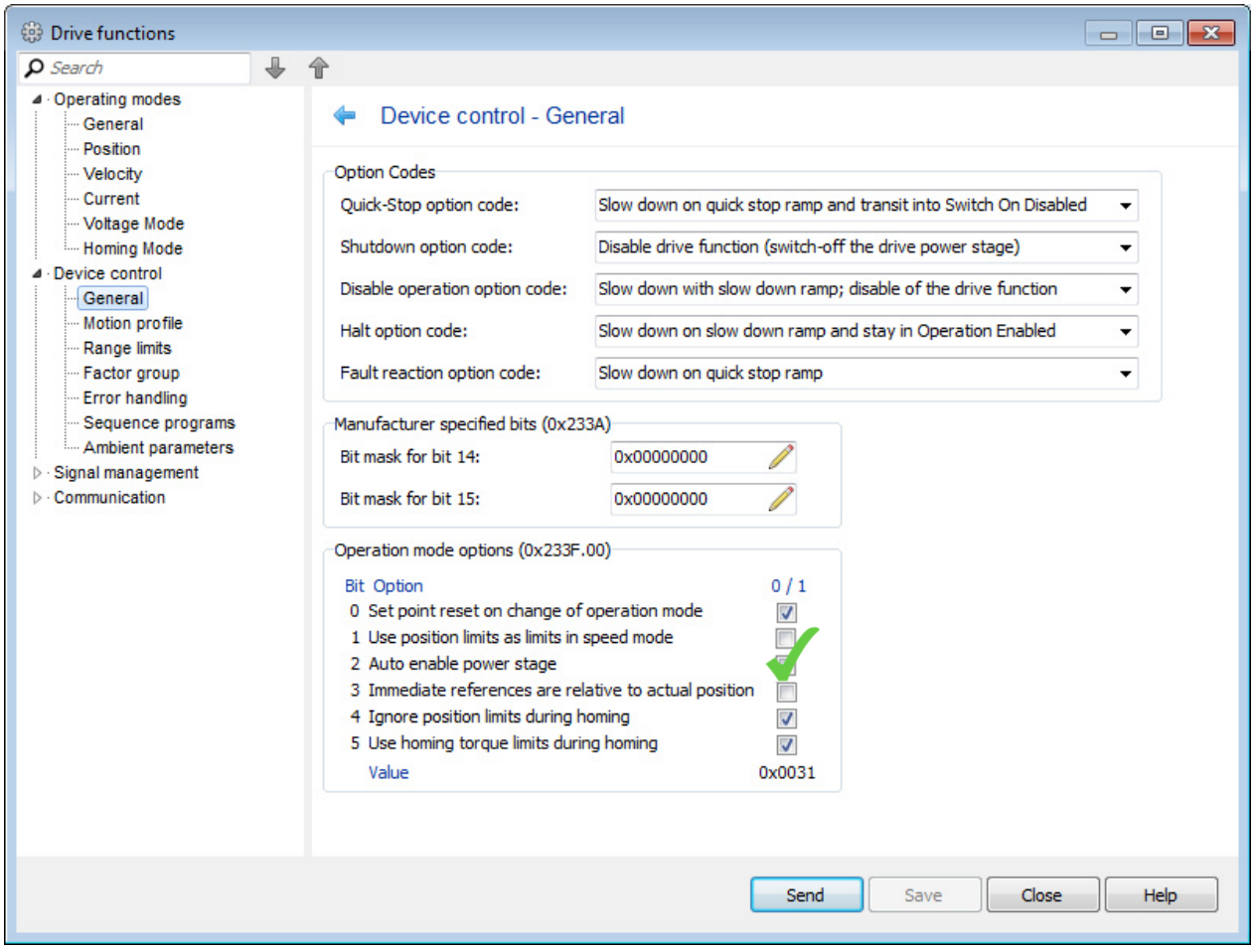


Figure 3 Auto-enable option at the General tab of the Drive functions / Device control

In these cases we might simply configure the Motion Controller to auto-enable the power-stage directly after reset and don't care about it at all (Figure 3).

In case of a thermal overload or in case of overvoltage the drive will protect motor and electronics by disabling the power-stage which is a direct transition from the Operation-Enabled state to Switch-On-Disabled.

An auto-enabled power-stage won't re-enable the drive after the problem is solved.

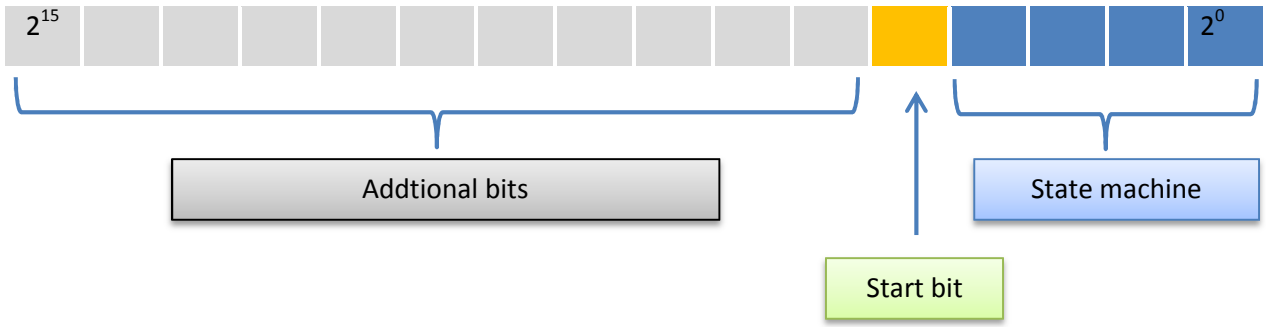
Dealing with the drive state machine

After a reset the drive will reach the Switch-On-Disabled state and wait for the user to switch on the drive.

If we explicitly want to enable the control and power-stage out of our program sequence, we need to send the appropriate commands by writing to the controlword. We have to monitor the actual state by reading the statusword, each being a 16 bit unsigned parameter.

Dealing with the controlword and statusword is a little complicated because it's a mix of different flags having different tasks (Figure 4).

Structure of the controlword



Structure of the statusword

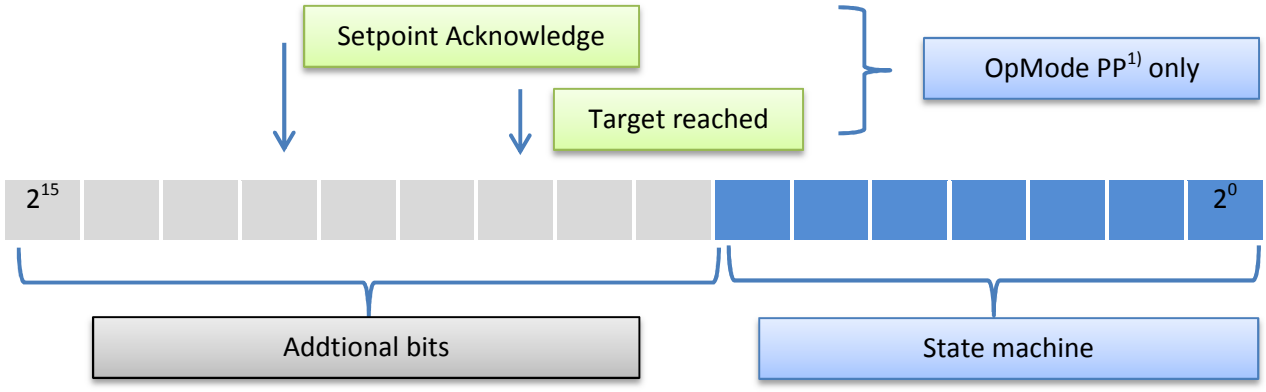


Figure 4 Contents of the statusword and control word of the servo-drive

[1)] see Table 4

To interact with the state-machine we have to code the commands in the lower 4 bits of the controlword and read the actual state out of the lower 7 bits of the statusword. So most likely some kind of bit masking

using bit oriented logic will be required within the scripts (see chapter patterns below). The reason for this structure is the limited bandwidth of field busses. Usually the controlword and the statusword are to be exchanged cyclically between master and slave and a compact combination of the most important flags helps to increase the update rate.

The commands coded in the lower 4 bits of the controlword are listed in Table 2; the actual state coding is listed in Table 3. The numbers of the transitions in Table 2 are the same as noted in Figure 5.

Command (transition)	controlword
Shutdown (2,6,8)	0x0006
Switch on (3)	0x0007
Enable Operation (4,16)	0x000F
Disable Operation (5)	0x0007
Disable Voltage (7,9,10,12)	0x0000
Quick Stop (11)	0x0002

Table 2 command sent to the drive state machine

State	statusword	bits						
Switch on Disabled	0x..40	1	0	0	0	0	0	0
Ready to switch on	0x..21	0	1	0	0	0	0	1
Switched on	0x..23	0	1	0	0	0	1	1
Operation Enable	0x..27	0	1	0	0	1	1	1
Quick Stop	0x..07	0	0	0	0	1	1	1
Fault	0x..08	0	0	0	1	0	0	0

Table 3 state machine states coded in the statusword

Enabling the drive (→ in Figure 5)

After a reset the drive will be in Switch on Disabled state. To enable the drive, which is a transition to the Operation Enabled state, we have to subsequently:

- send the Shutdown command (0x 00 06)

- at last send the Enable Operation command (0x 00 0F)[2].

Disable the power-stage (→ in Figure 5)

To simply disable the power-stage, a Disable Voltage command is best suited. It will switch to the Switch on Disabled state out of most states.

- Send Disable Voltage (0x 00 00)

Stop the Motor and Disable the power-stage (⟶ in Figure 5)

To explicitly stop the drive and then disable the power-stage the easiest way is to switch the drive into the Quick-Stop state. The method how to stop the drive is configured using the object Quick Stop Option Code (0x605A.00). Default is: stop at quick stop ramp and disable the power-stage.

- Send Quick-Stop command (0x 00 02)
- Transition to Switch on Disabled will be done automatically after the drive has been stopped.

Transition between states might take some time. If the drive is going to be disabled the motor might have to be stopped and a configured brake might need some time to be activated. Therefore before sending a next command to the state-machine it is important to check the actual state. Commands will be ignored if no related transition is available in the current state.

Even if a script is planned to be auto-started directly after the reset of a drive, during development and test, the drive might actually be in a state different from the Switch on Disabled when the script is started. To ensure a proper start it might be a good idea to send a Disable Voltage directly at the start of the program sequence.

[2] The switch on command is not necessary for a FAULHABER Motion Controller. The purpose of the switch on command in a servo drive is to enable the motor power supply. As the drives are directly connected to a low voltage power supply there is no need to control a mains contactor.

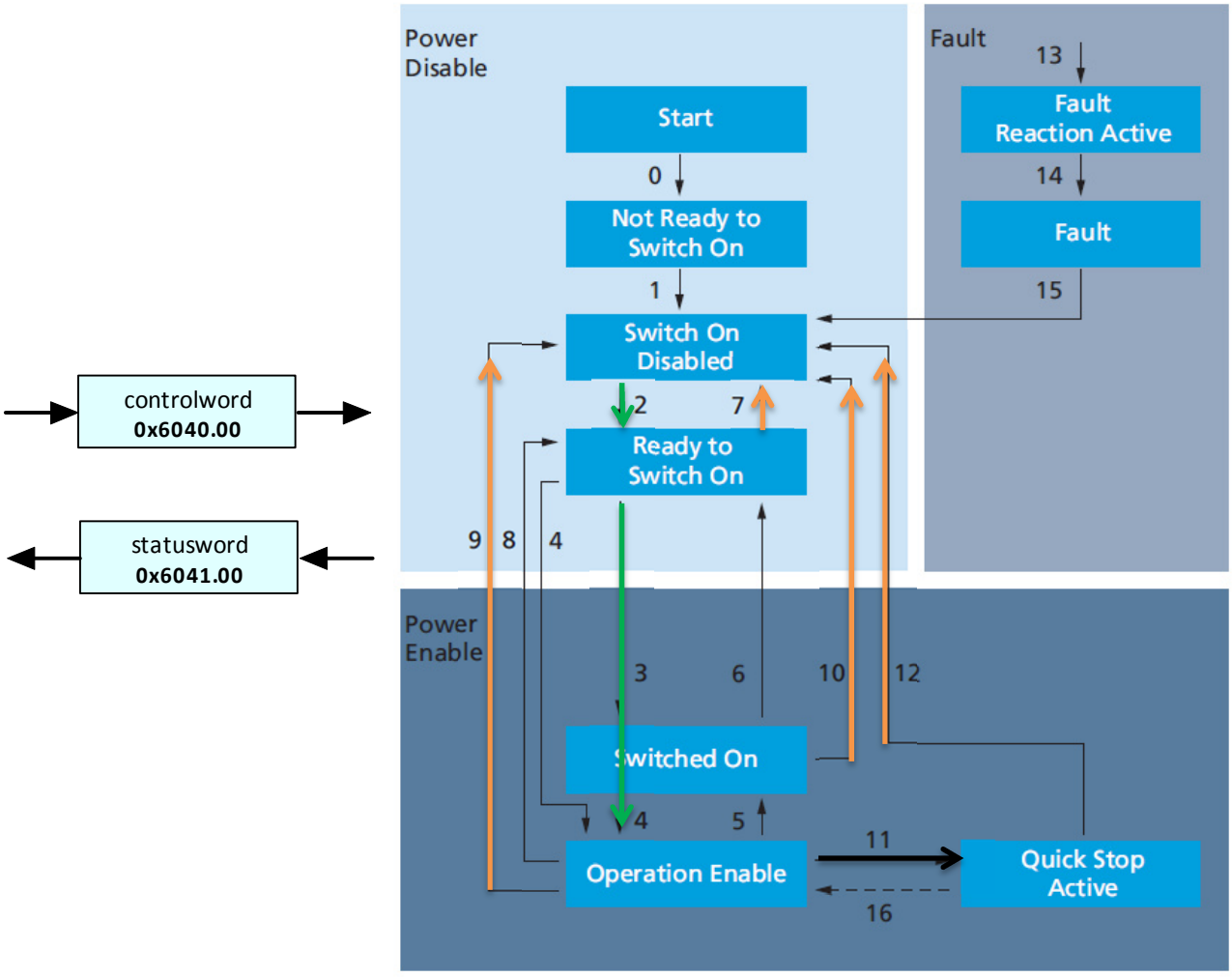


Figure 5 Drive machine state of a CiA 402 servo-drive

Control OpModes

Switching between different OpModes can be done by writing the OpMode to the Modes of Operation parameter (0x6060.00). The currently active one can be read out of the Modes of Operation Display (0x6061.00) but that's usually not necessary.

Operating Mode		Modes of Operation
ATC	**A**nalog **T**orque **C**ontrol	-4
AVC	**A**nalog **V**elocity **C**ontrol	-3
APC	**A**nalog **P**osition **C**ontrol	-2
Volt	Direct **Volt**age Mode	-1
-	Control disabled	0
PP	**P**rofile **P**osition	1

PV	**P**rofile **V**elocity	3
Homing	**Homing** Mode	6
CSP	**C**yclic **S**ynchronous **P**osition	8
CSV	**C**yclic **S**ynchronous **V**elocity	9
CST	**C**yclic **S**ynchronous **T**orque	10

Table 4 List of available OpModes

So if we want to start with a homing sequence and switch to APC afterwards the commands would be:

- (Start the drive if not done automatically)
- Set OpMode Homing: **SETOBJ $6060.00 = 6**
- Start the homing by writing a positive edge to bit 4 of the controlword and wait for the homing sequence to be finished
- Set OpMode APC: **SETOBJ $6060.00 = -2**

Speed control out of a script can either be done using **CSV** or **PV** mode.

PV mode will respect the limits of acceleration and deceleration, **CSV** will not. As there is no penalty for the **PV** in terms of additional commands, consider using **PV** out of scripts.

Position control out of a script can either be done using **CSP** or **PP** mode.

PP mode will respect the limits of acceleration and deceleration and profile speed but does require the motion to be started explicitly by generating a positive edge in the start bit of the controlword (Figure 4). So **PP** usually is the more comfortable OpMode but does require additional steps (see examples).

Differences between local BASIC scripts and remote control

PLC based automation has to use one of the communication interfaces to access the parameters. After the startup CANopen and EtherCAT rely on PDOs to exchange a predefined set of parameters. Data exchange between the communication and the program is then done by means of global variables. The execution of the PLC program and the communication will not be synchronized unless an explicit SDO read or write has been implemented. So even if a command is written to the variable representing the controlword this does not imply the value is sent immediately to the slave. Consequently, if we need to send a sequence of values to a single parameter e.g. to set the start bit in the controlword and reset it again, a PLC program always needs to explicitly check the reaction of the drive in the status word.

Even using a .vbs script out of the FAULHABER Motion Manager we have to check the response of the drive after each command to avoid a communication overload.

These precautions are not necessary for controller based BASIC scripts. Each write-access to a parameter using the SETOBJ will be executed at the very same time when the program line is interpreted. The next line is executed only, if the previous one is completed, so there is a strictly synchronous behavior and no communication overload.

The FAULHABER MC BASIC

The BASIC dialect

FAULHABER Motion Controller V3.0 uses a BASIC dialect to code scripts that can be executed directly at the controller. The Motion Controller interprets each line and executes the code. There is no compilation involved. However the development-environment integrated into the Motion Manager implements some preprocessing of the scripts. Direct download of scripts without using the Motion Manager is not supported. Debugging and single stepping are supported by the FAUHABER Motion Manager using any of the supported communication interfaces (USB, RS 232, CANopen).

Please refer to the programming manual to get additional information about the debugging support of the FAULHABER Motion Manager.

Main features of the scripting environment are:

- Support of standard BASIC control structures
- BASIC dialect extensions
  - to read and write of drive parameters
  - to deal with bit-wise logic
  - to add time measurement and dead-time handling
- Up to 8 programs can be stored at the MC
- One of the stored programs can be configured to be auto-started after a reset of the drive
- Access to the programs can be protected by a key-parameter
- Up to 26 global variables (a … z) can be used
  - can be stored in / re-loaded out of the internal EEPROM using **SAVE** or **LOAD** and a comma separated list of variables
  - can be directly accessed by a master system via the object 0x3005.xx in the Object dictionary
- Local variables can be declared using the DIM key-word
- FUNCTIONs are supported
  - Can use local variables
  - Can return a numeric value

SAVE / LOAD stores the variables in the internal parameter EEPROM of the Motion Controller. It is important to keep the limited write cycles of such a EEPROM in mind. So if we assume a maximum of 10^6 write cycles and do save the counter value of an on-time counter every 1 second, the limit is reached after less than 2 weeks of 24/7 operation!

Control structures and operations

The purpose of a local script is either to execute a sequence of operations automatically (like a batch of commands) or to cyclically execute a control sequence, react to states and inputs and branch into different actions.

Control structures

IF/ELSE/END IF	FOR … NEXT	DO … LOOP

IF … THEN
…
END IF
	FOR i = 1 To n
	…
	NEXT i
		DO
		…
		LOOP

```
'Read Inputs
a = GETOBJ $2311.01

IF (a = 1) THEN
   'Input 1 is set
   …
ELSE
   …
END IF
```

```
:Init
SETOBJ …
SETOBJ …

DO
'Read Inputs and states
'processing
LOOP
```

a label

Figure 6 Control structures if/else and loop

Logic operations are

- Standard logic: AND, OR, NOT
- Bit-wise logic: &, |, ~
- Compare: <, >, <>, =, >=, <=

Simple arithmetic[3]

- +, -, /, *
- % modulus

Read and write drive parameters

- SETOBJ <index>.<Sub> = <value> e.g.: SETOBJ $607A.00 = 10000
- a = GETOBJ <index>.<Sub> e.g.: a = GETOBJ $2311.01

[3] All variables are treated as signed 32 bit integer numbers

Restrictions

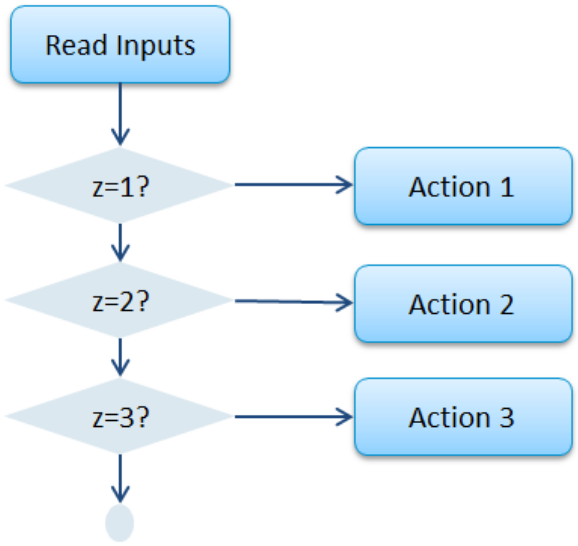
Main purpose of the Motion Controller is the motor control. The resources of the additional scripting engine are therefore limited. Restrictions are:

- The up to 8 programs cannot call each other
- Names of the global variables are a – z lower case. Additional variables having symbolic names can be declared using the DIM key-word
- You can't use **GOTO** to jump out of a **IF**/**ELSE**, a function call or a **GOSUB** are supported
- You can't use **GOTO** to jump out of a **FUNCTION**
- Firmware versions up to revision H do support up to 3 nested **IF**/**ELSE** levels. Firmware starting from revision I supports up to 15 levels.
- The size of a single program sequence is limited to 4kB. Firmware starting from revision J supports 8kB of space for a single script.

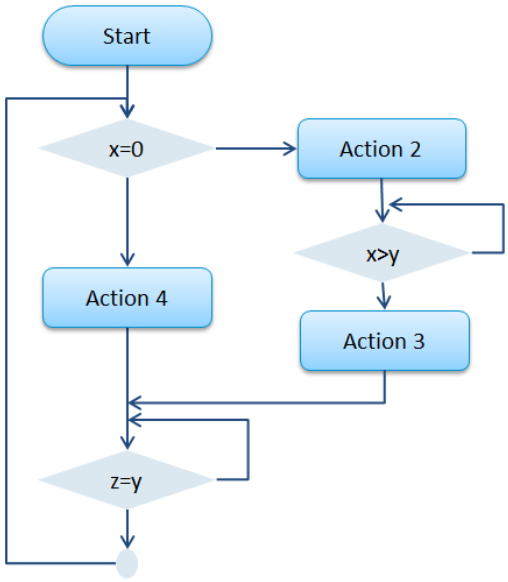
Patterns for embedded scripts

There are some recommended strategies on how to create a control flow of a program and some typical patterns like reacting to a single bit of an input that are different from standard BASIC environments. While it is not mandatory to use them, the use of these patterns is encouraged and represents the intended use of the environment.

Step Sequence vs Flow chart

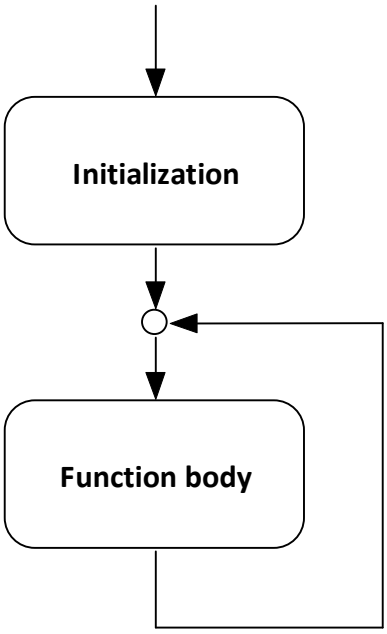


Step sequence



Flow Chart with micro loops

Figure 7 Basic control structures for a script



The overall control structure can of course be a traditional flow chart type with micro looping where necessary. Such a micro loop usually will include polling one of the parameters like the statusword or a digital input and waiting for a position being reached or an input being active. Drawback however is, while being stuck in the micro loop it's difficult to react to additional inputs or changes.

PLC environments or even the popular Arduinos use a different approach which we feel is more appropriate for embedded control.

The main structure of these systems is an Initialization executed once at startup and a subsequent main loop executed either triggered by a time (PLC task) or executed continuously.

Figure 8 suggested main loop structure of a BASIC script

The recommendation is to use a continuously executed main-loop and combine it with a step sequence as in the left side of Figure 7. The main advantage compared to the flow chart on the right side of Figure 7 is that there are no longer blocking loops.

In a main-loop + step-sequence you can simultaneously wait for reaching a position while checking a time-out and waiting for any of the digital inputs to change. Additionally these step-sequences are well suited to interact with the bit-wise handshake of the controlword and statusword.

Enable and Disable the power stage

Enabling the power-stage requires only a few commands to the device-control via controlword. As mentioned, we do have to check the initial state though.

So a pattern could be:

- Ensure a defined state at the beginning
- If we are in switch on disabled state (which is the default) and whatever start condition is reached:
  - Send the startup sequence
  - Start waiting for being enabled
- If we are enabled check whatever shutdown condition is defined
  - Send any of the shutdown commands
    Quickstop or
    disable voltage

```
'-----------------------------------------
'Author:  MCSupport
'Date:    02/05/2019
'-----------------------------------------
'Description:  Enable the drive
'-----------------------------------------
#INCLUDE "MotionParameters.bi"
#INCLUDE "MotionMacros.bi"

'use a step-counter TO step through the sequence
#DEFINE eStepInitial 0
#DEFINE eStepWait4Enableld 1
#DEFINE eStepOperational 2

DIM StepCounter = eStepInitial

DIM DriveStatus

'send a reset to the state-machine because the program
'could have been started in any state of the device
SETOBJ Controlword = CiACmdDisableVoltage

'infinite LOOP
DO
   'read the statusword
   DriveStatus = GETOBJ Statusword
   'and mask the bits for the state-machine
   'this uses bit-wise logic and will cut the lower 7 bits
   DriveStatus = DriveStatus & $7F

   IF (StepCounter = eStepInitial) THEN
      'check for switch on disabled and a start condition
      IF(DriveStatus = CiAStatus_SwitchOnDisabled) AND (…) THEN
         'we now are in switch on disabled state
         'send the startup sequence
         'first the shutdown
         SETOBJ Controlword = CiACmdShutdown
         'send the enable command next. No wait necessary here - we are
         'synchronous
         SETOBJ Controlword = CiACmdEnableOperation
         'switch to a waiting state
         StepCounter = eStepWait4Enableld
      ENDIF
   ELSEIF (StepCounter = eStepWait4Enableld) THEN
      IF(DriveStatus = CiAStatus_OperationEnabled) THEN
```

```
            'enable operation is reached
            'switch out of the waiting state
            StepCounter = eStepOperational
        ENDIF
    ELSEIF (StepCounter = eStepOperational) THEN
        'check whatever to disable
        IF (…) THEN
            'send the quick stop
            SETOBJ Controlword = CiACmdQuickStop
            'switch to wait for reset
            StepCounter = eStepInitial
        END IF
    END IF

    'do whatever is intended

    'loop back to the start of the main-loop
LOOP
```

Using the Motion-Lib

There is a set of files coming with the Motion Manager which eases the job here.

One of these is the `MotionParameters.bi` which is included at the top of the script and introduces a common set of symbolic names, e.g. `#DEFINE Controlword $6040.00`.

The next is `MotionMacros.bi` using single line macros to offer shortcuts for typical actions like reading and evaluating the statusword or writing specific commands to the controlword. So enabling the power-stage can then be written as:

Full sequence for enabling the power-stage	Using the macros
`SETOBJ Controlword = CiACmdShutdown` `SETOBJ Controlword = CiACmdEnableOperation`	`MC.Shutdown` `MC.EnOp`

`MotionParameters.bi` and `MotionMacros.bi` are an integral part of the BASIC environment and are included by default in new script files. They can't be changed by the user. Users can create a copy and customize them, of course.

Last is a file `MotionFuctions.bi` which is part of the examples delivered by the Motion Manager. This one contains a set of functions that can be used for typical interaction like enabling or disabling the power stage, starting a movement, waiting for being in position.

Using the Enable() function out of the `MotionFuctions.bi` the example above would be shortened to:

```
'----------------------------------------
'Author:  MCSupport
'Date:    02/05/2019
'----------------------------------------
'Description:  Enable the drive
'----------------------------------------
#INCLUDE "MotionParameters.bi"
#INCLUDE "MotionMacros.bi"
#INCLUDE "MotionFunctions.bi"

'infinite LOOP
DO
   'check for a start condition
   IF (…) THEN
      Enable()
   'check whatever to disable
   ELSEIF (…) THEN
      QuickStop()
   END IF

   'do whatever is intended

   'loop back to the start of the main-loop
LOOP
```

Typical use of program variables

The MC BASIC offers 26 global variables – lower case letters. This does not really help to create a well readable script but these variables are special as they do have a fixed position in the environment. Therefore they can be saved and re-loaded to and from the EEROM as well as mapped to a PDO. Using the `#DEFINE` mechanism symbolic names can be assigned to these variables:

```
#DEFINE TargetPos a
```

Will assign the name TargetPos to the global variable a, which can then be mapped to a PDO.

In addition to these special global ones, variables having a symbolic name can be declared using the `DIM` key-word either in the main-sequence or in a function.

Using `DIM variablename` will create a global variable or a local one – depending on whether used in a function or in the main-sequence.

Only the global variables a … z can be used for special functions like the special timers and the event-handling. You might of course use symbolic names assigned using `#DEFINE` in these cases too.

React to flags and digital Inputs (bit-wise logic)

Another pattern typical for embedded applications is bit-wise logic. Quite often there are some flags combined in a single variable. We have already seen this in the controlword and the statusword.

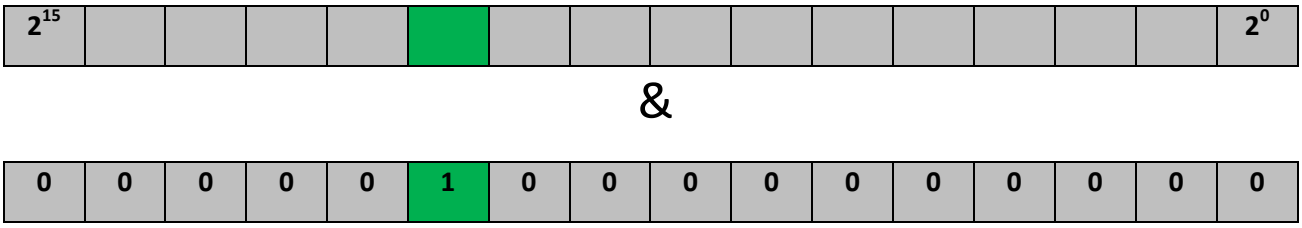
In the statusword we need to check the lower 7 bits to know in which state we are, but then there are the bit 10 and the bit 12 that are used in some of the OpModes for a hand-shake.

So e.g. in PP-mode if we want to check, whether we did reach the target position, we need to check for bit 10. We even have to be careful in a sequence of positon steps bit 10 might be set because we did reach the previous target position. If we now want to check for the next one, we do need two steps:

- Wait for bit 10 being cleared – move started
- Wait for bit 10 being set again – we reached the new position

Anyway, we need to check bit 10 and don't really care for the other bits. In order to cut the bit 10 only we use a bit-wise logic and evaluate

result.bit$_x$ = statusword.bit$_x$ & mask.bit$_x$



The code would be

```
'read statusword
DriveStatus = GETOBJ Statusword
'mask bit 10 and check
IF (DriveStatus & CiAStatus_InPosBit) THEN
   'do whatever is intended
ENDIF
```

React to edges: an action taken only at a rising or falling edge

Sometimes it is necessary to do actions only at the edge of an input signal – statusword or digital input.

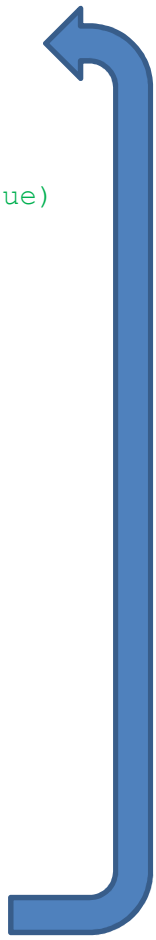
Checking the change of a bit involves bit-wise logic again but also needs a copy of the previous value of the variable to be checked. So to have an example let's enable the power-stage at the positive edge of DigIn1 and disable it again at the negative edge:

We need to read the digital inputs

rising edge	check for newly set bits and mask only the one representing DigIn 1
falling edge	check for newly cleared bits and mask only the one representing DigIn 1

The code would be:

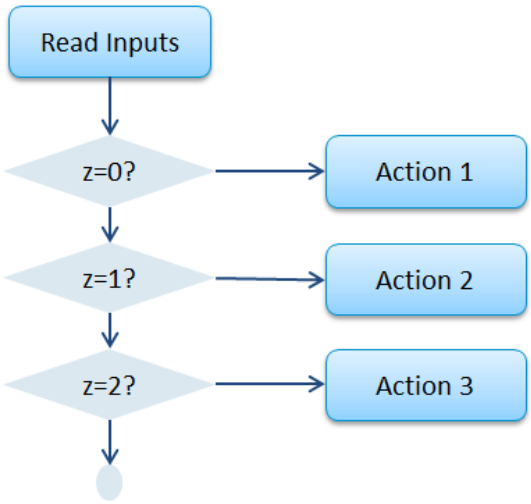
```
DIM DigInCurrent = 0
DIM DigInLast = 0

DO
   'read digital inputs
   DigInCurrent = GETOBJ DigitalInputLogicalState
   'check for newly set bits by evaluating (new value) & ~(old value)
   'and only use the lowest bit in the result
   IF ((DigInCurrent & ~ DigInLast) & $01) THEN
      'send enable sequence
   END IF

   'check for newly cleared bits by evaluating
   '(old value) & ~(new value)
   'and only use the lowest bit in the result
   IF ((DigInLast & ~ DigInCurrent) & $01) THEN
      'send disable command
   END IF

   'now save the new values for the next turn
   DigInLast = DigInCurrent

LOOP
```



Use Sub-routines

Starting from revision J the firmware of the Motion Controller supports standard FUNCTIONs as a part of the script. We already used some of them in the example above.

FUNCTIONS can be used to improve the structure of a script – it will be better readable.




```
DIM StepCounter = 1
DO
   IF StepCounter = 1 THEN
      Action_1()
   ELSEIF StepCounter = 2 THEN
      Action_2()
   ELSEIF StepCounter = 3 THEN
      Action_3()
   END IF
LOOP

FUNCTION Action_1()
'Step 1: if requested state is reached, increase step counter by one
Status = GETOBJ StatusWord
IF Status = Whatever THEN
   StepCounter = 2
ENDIF
END FUNCTION

FUNCTION Action_2()
…
END FUNCTION

FUNCTION Action_3()
…
END FUNCTION
```

Figure 9 Use of sub-routines to execute the different steps of a script

Using functions can also improve the performance. In this case the time to read and interpret the main-loop is shorter compared to an implementation where the different actions are directly coded into the **IF** / **ELSEIF** / **ELSE** construct of the step-sequence in the main-loop.

Create your own program

When you start thinking about stand-alone automation don't start coding directly. BASIC or whatever scripting language is far from being intuitive. Therefore it's much easier to start drawing.

You could start identifying the primary steps or states your application will be in (Figure 10). This is an example implementing a brake/enable function. **DigIn1** is used as an enable input; **DigIn2** is the brake-input. At the positive edge of **DigIn1** the drive shall be enabled, a negative edge of **DigIn2** shall force the drive to be actively stopped. The drive might be reactivated out of the stop if the brake-input is back again (positive edge). The drive shall be disabled at the negative edge of the enable input.

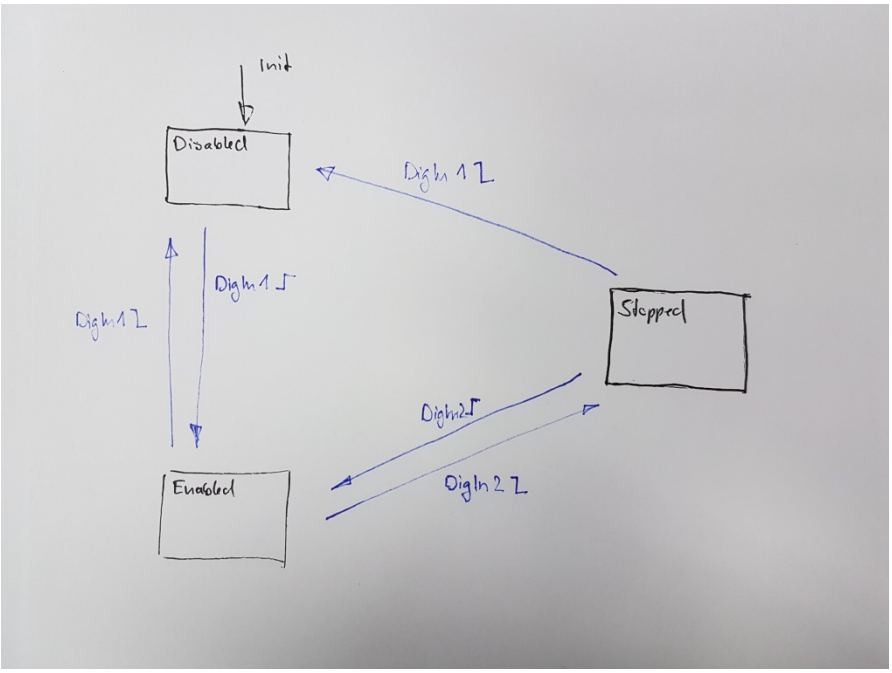


Figure 10 a first approach for a brake / enable program

Drawing here means take a sheet of paper and some colors and

- start with blocks for the steps or states of the action.
- add transitions and conditions
- add actions within the steps/states and at the transitions

If we have to implement some kind of handshake between our program and the MC: e.g. when using PP or enabling the power-stage we might need to add some intermediate steps. So add these steps to your sketch and re-apply transitions, conditions and actions (Figure 11). This is the program logic that can be executed in the main-loop of Figure 8.

What are the preconditions for the script? You might need to add some initial actions to create a defined configuration of the controller and add them to the init step of Figure 8.

Alternatively you could use a flow chart to describe the control flow of a script. Again start with simple action-blocks and branches and refine your model. Add the conditions and a text form of the actions.

These graphical representations are well suited to “simulate” the behavior.

Only if you are satisfied with the “simulation”, start coding. In most of the cases this will now be only a task of writing down the graphical control flow. Of course we now need to check for whatever bit-masks we might need and which numbers the used parameters do have.

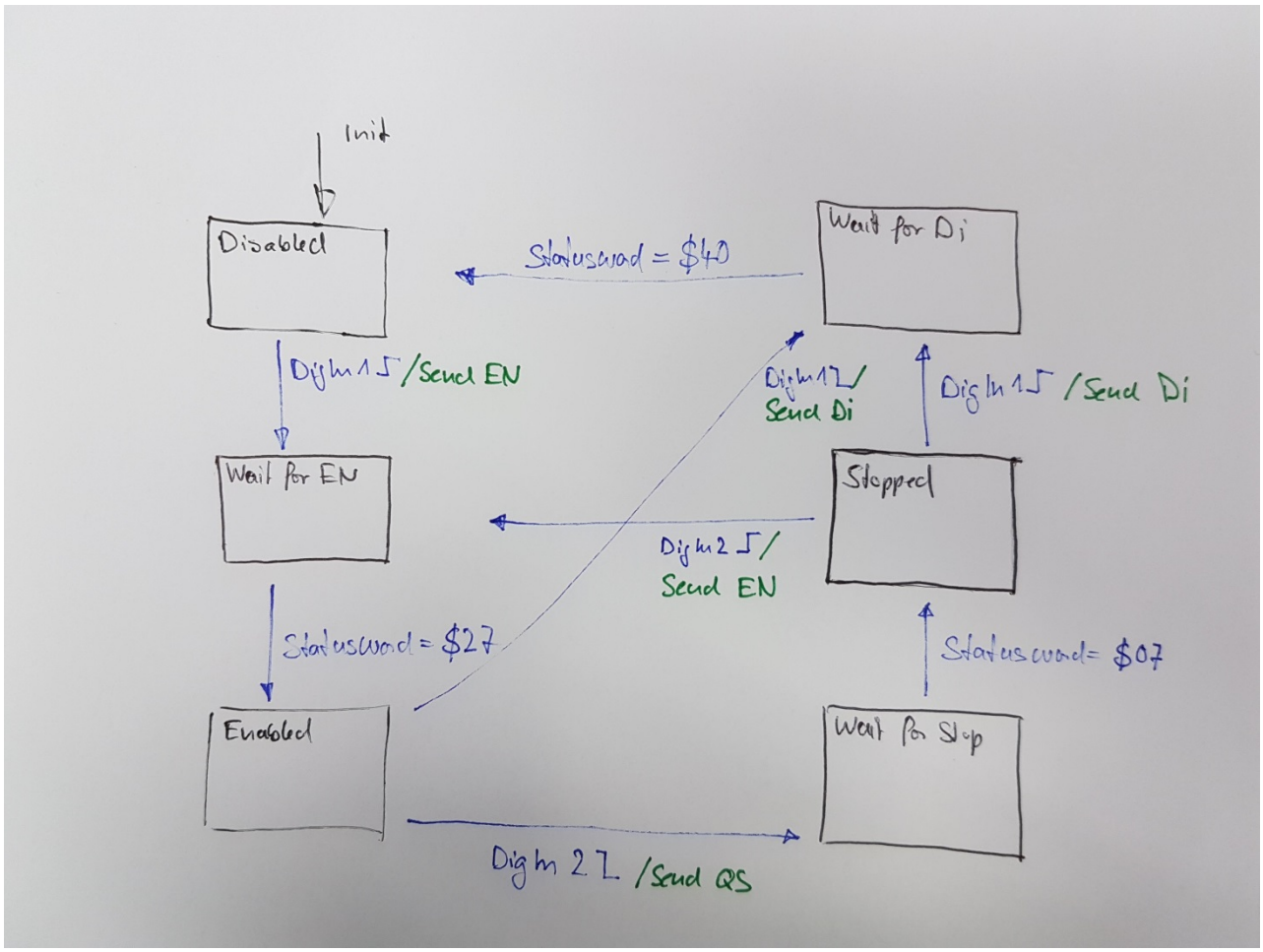


Figure 11 refined diagram having conditions, actions and intermediate steps

Example A (switch between two absolute positions)

The purpose here is to

- start the drive in reaction to a digital input,
- execute a homing sequence using the lower limit switch as a reference,
- and cyclically move between two positions while also cyclically changing the profile parameters for acceleration and deceleration.
  The used OpMode is ProfilePosition Mode (0x6060.00 = 1).

This requires enabling the controller in a **first** step **then** executing a homing sequence **then** sending the target positions **then** waiting for being in position and updating the profile parameters.

So there are several steps to be taken. A well suited solution pattern for such a problem is a step sequence. A step **sequence is a pattern, where only a part of the program is executed in each update cycle, depending of the step in which** the program is.

In a PLC environment there is a special diagram to design these step sequences: sequential function chart (SFC). Here however we use an **IF** / **ELSEIF** / **ELSE** construct.

```
IF (StepVariable = xxx) THEN
…
ELSEIF (StepVariable = xxx) THEN
…
END IF
```

In the example DigIn1 is used to enable/disable the drive whereas DigIn3 is used as the lower limit switch used for the homing sequence.

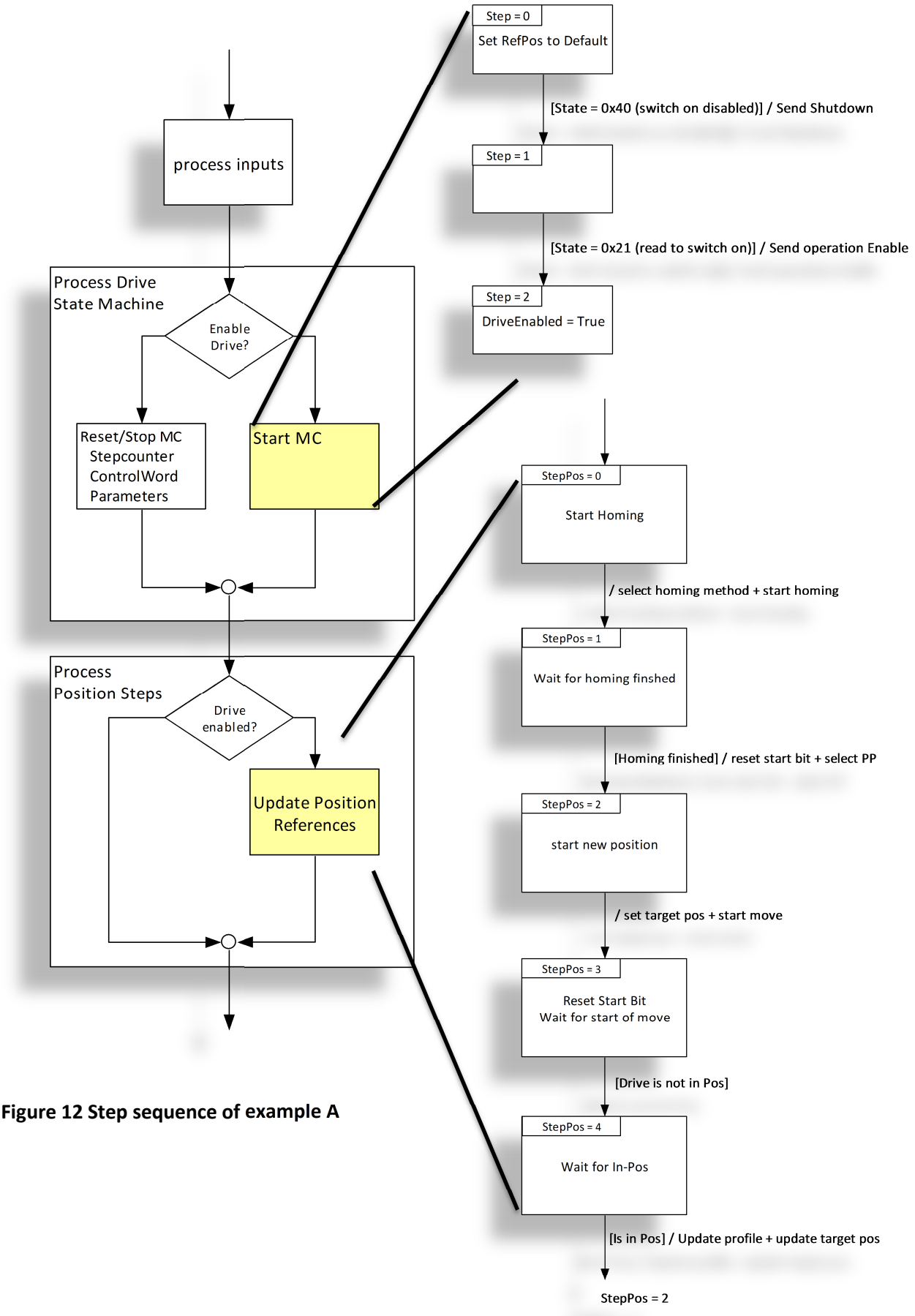
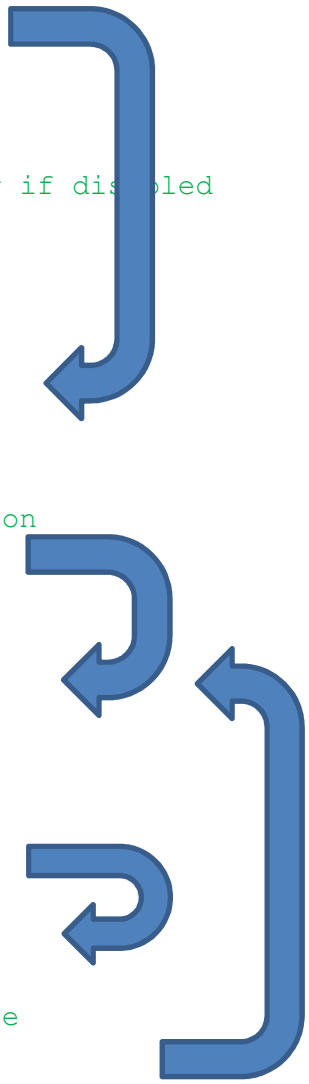


Figure 12 Step sequence of example A

```
'-----------------------------------------
'Author      : FAULHABER MCSUPPORT
'Date        :  2019-02-05
'-----------------------------------------
'Description :  Do a reference and then step positions
'               DigIn1 enables/disables the movement
'               DigIn3 is used as the lower limit switch during homing
'-----------------------------------------
#INCLUDE "MotionParameters.bi"
#INCLUDE "MotionMacros.bi"
#INCLUDE "MotionFunctions.bi"

'-----------------------------------------
' global variables
DIM StepCounter = 0
#DEFINE eStepStart 0
#DEFINE eStepDoRef 1
#DEFINE eStepRun 2

DIM TargetPos = 10000
DIM ACC = 10
DIM DEC = 10
DIM DeltaAcc = 10

'profile speed is constant
#DEFINE ProfileSpeed 2000

'max ACC/DEC
#DEFINE MaxAccDec 500
#DEFINE MinAccDec  10


'-----------------------------------------
' additional functions

'-----------------------------------------
' SetProfile()
' used to set the profile generator to a new
' set of paramters

FUNCTION SetProfile(newACC, newDEC, newSpeed)
   SETOBJ ProfileVelocity = newSpeed
   SETOBJ ProfileAcc = newACC
   SETOBJ ProfileDec = newDEC
END FUNCTION

'-----------------------------------------
' ConfigureDigIn()
' used to configure the DigIn settings by the script
' usually not part of a script but done using the MoMan

FUNCTION ConfigureDigIn()
   'config lower limit switch
   'this is bit coded - here input 3
```

```
   SETOBJ $2310.01 = 4
   'config upper limit switch to none
   SETOBJ $2310.02 = 0
   'Polarity = strait
   SETOBJ $2310.$10 = 0
   'Threshold = TTL
   SETOBJ $2310.$11 = 0
END FUNCTION

'--------------------------------------------
' StartHoming()

 FUNCTION StartHoming()
   SETOBJ HomingMethod = 17
   SETOBJ ModesOfOperation = OpModeHoming
   SETOBJ Controlword = (CiACmdEnableOperation | CiACmdStartBit)
END FUNCTION

'--------------------------------------------
' isInRef()

FUNCTION isInRef()
   DIM DeviceStatus

   DeviceStatus = GETOBJ Statusword

   'check for IsInRef bit
   IF (DeviceStatus & $1000) > 0 THEN
      RETURN 1
   ELSE
      RETURN 0
   END IF

END FUNCTION

'--------------------------------------------
' isInPos()
' check whether the move is finished - non blocking

FUNCTION isInPos()
   'check for IsInRef bit
   IF (GETOBJ Statusword & CiAStatus_InPosBit) > 0 THEN
      RETURN 1
   ELSE
      RETURN 0
   END IF
END FUNCTION

'--------------------------------------------
' The Main-Loop

:Init
ConfigureDigIn()
```

```
DO
   'check whether we shall start
   IF (StepCounter = eStepStart) AND MC.DigIn1 THEN
      'Enable() is a blocking call - will return only if enabled
      Enable()
      StepCounter = eStepDoRef
   END IF

   'check whether to stop again
   IF NOT MC.DigIn1 THEN
      'Disable() is a blocking call - will return only if disabled
       Disable()
       StepCounter = eStepStart
   END IF

   'do the movement
   IF (StepCounter = eStepDoRef) THEN
      'power is enabled - start the homing
      StartHoming()
      IF isInRef() THEN
         'we are in ref and switch to the main operation
         StepCounter = eStepStartMove
         'Switch to PP-mode
         SETOBJ ModesOfOperation = OpModePP
      END IF
   ELSEIF (StepCounter = eStepStartMove) THEN
      'update the profile values
      SetProfile(ACC,DEC,ProfileSpeed)
      'start a new move - non immedeate
      MoveAbs(TargetPos,0)
      'next step: wait for being in pos
      StepCounter = eStepWaitPos
   ELSEIF (StepCounter = eStepWaitPos) THEN
      'wait for being in target
      IF isInPos() THEN
         'after being in target we move to the opposite
         TargetPos = (-1)*TargetPos
         StepCounter = eStepStartMove

         'and increase the ACC/DEC by the step-width
         ACC = ACC + DeltaAcc
         DEC = DEC + DeltaAcc

         'if the max or min acceleration rate is reached
         'invert the step direction
         IF (ACC = MaxAccDec) THEN
            DeltaAcc = (-1)* DeltaAcc
         ELSEIF (ACC = MinAccDec) THEN
            DeltaAcc = (-1)* DeltaAcc
         END IF
      END IF
   END IF
LOOP
```



Example B (create a motion profile)

The purpose of this example is to enable the power stage and select PP mode. Then a motion profile is created by

Step 1:

- set an absolute target position A to 0 and
- set the target window time to 500ms
- start the move

Step 2: (if position A reached)

- set an absolute target position B of 40,000 increments
- set target window time to 20ms
- start the move

Step 3 (if position B reached)

- set an absolute target position B of 45,000 increments
- set target window time to 100ms
- start the move

Step 4:

- restart with step 1

In this example no profile parameters are changed between the different moves. But of course this could have been added easily.

Figure 13 Cyclic motion profile of example B

Again a step sequence is the best suited pattern as we have to wait for the drive signaling a target reached before we start the next step.

```
'--------------------------------------------
'Author      :  FAULHABER MCSUPPORT
'Date        :  2019-02-05
'--------------------------------------------
'Description :  create am movement profile
'--------------------------------------------
#INCLUDE "MotionParameters.bi"
#INCLUDE "MotionMacros.bi"
#INCLUDE "MotionFunctions.bi"


DIM TargetPos

#DEFINE TargetPosWindowTime $6068.00


:Init
'OpMode = PP
SETOBJ ModesOfOperation = OpModePP
'no limit switches
SETOBJ $2310.01 = 0
```

```
SETOBJ $2310.02 = 0

Enable()

'movement:
'move to abs 0 - after 500ms
'move to abs 40000 - after 20ms
'move to abs 45000 - after 100ms
DO
   TargetPos = 0
   'Set Target Window Time
   SETOBJ TargetPosWindowTime = 500
   'now move start the movement to the first pos
   MoveAbs(TargetPos,0)
   'wait for being in pos
   WaitPos()


   TargetPos = 40000
   'Set Target Window Time
   SETOBJ TargetPosWindowTime = 20
   'now move start the movement to the second pos
   MoveAbs(TargetPos,0)
   'wait for being in pos
   WaitPos()

   'send the NEXT target pos - non immediate
   TargetPos = 45000
   'Set Target Window Time
   SETOBJ TargetPosWindowTime = 100
   'now move start the movement to the last pos
   MoveAbs(TargetPos,0)
   'wait for being in pos
   WaitPos()

LOOP
```

Additional Patterns

After the first successful steps seen in the examples, the expectations might increase. Some additional options and techniques might help.

Asynchronous reaction to events

In a main-loop structure according to Figure 8 it's easy to cyclically check whatever condition the drive might be in. Additionally it's possible to register one of the subroutines as a handler for any condition signaled in the device status word 0x2324.01. To check the collection of information in this 32 bit word, open the FAULHABER Motion Manager Status Display or refer to the manual.

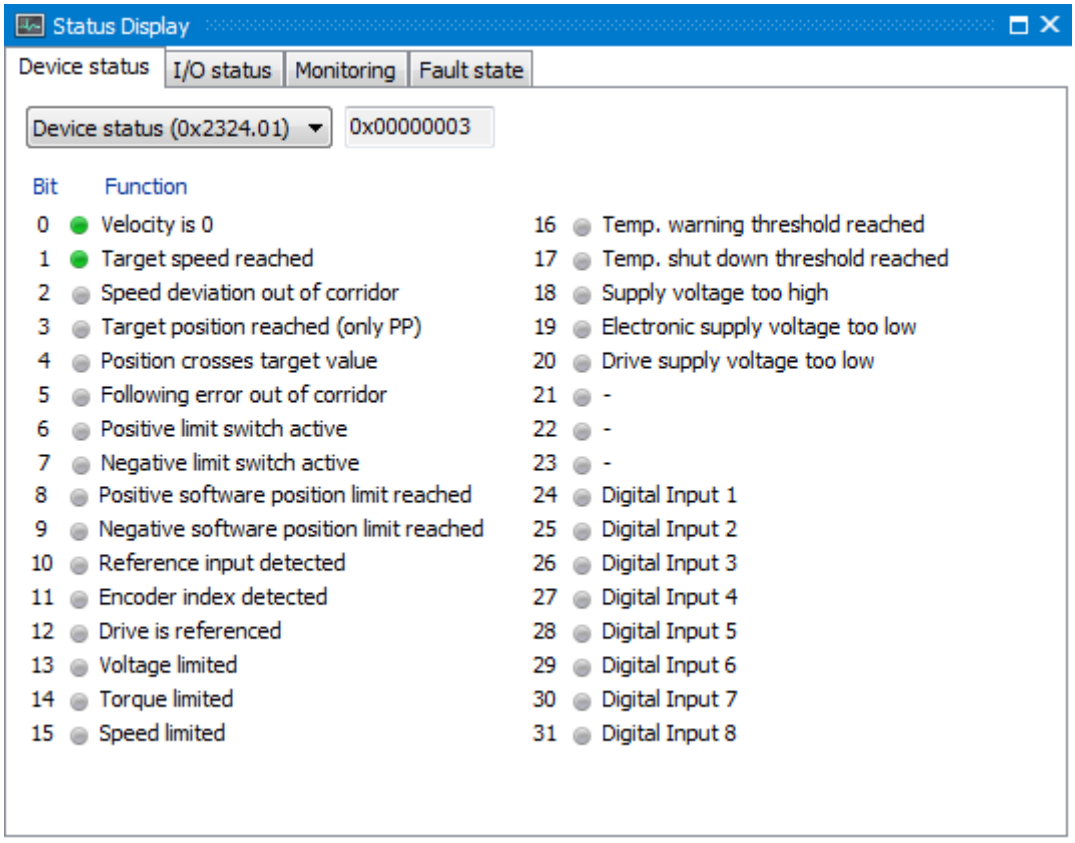


Figure 14 bits collected in the device status word 0x2324.01

A single handler for any combination of bits in this device status word can be registered:

There are four extended commands to support this:

Key word	Description
EN_EVT	Registers a subroutine identified by a label to be the handler for a certain combination of bits within the device status word. `EN_EVT $00010000, OverTemp` Will register the subroutine at the label OverTemp to be executed if the Temp warning bit is set.
DI_EVT	Disables the event from further calls
DEF_EVT_VAR	Defines a variable to be used in the event processing. During each call, the contents of the device status word will be copied into the event variable `DEF_EVT_VAR e` Will define variable e to be the variable used by the event processing.
RET_EVT	Returns out of the event-handler back to the next line of the main program

Code example

```
:Init
…
DEF_EVT_VAR s
EN_EVT $00010000, OverTemp

DO
…
…
…
LOOP

:OverTemp
'do whatever seems appropriate
RET_EVT
```

Add time-outs and time measurement

Time-outs

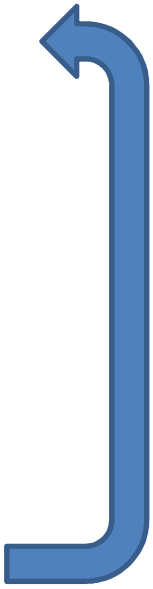
MC based scripts are executed without any specific timing behavior, simply as fast as possible. Sometimes however, a defined timing might be required e.g. in the case of a time-out.

A main-loop + step-sequences type of scripting allows for different conditions to be checked in each execution. So it would be easy to check a timeout and simultaneously check for being in position. To implement time-outs a BASIC extension can be used. Key commands are:

Key word	Description
DEF_TIM_VAR	Defines one of the variable to be used by the timer `DEF_TIM_VAR t` Will define the variable t to be used by the timer
START_TIM	Sets the defined timer variable to the given value and starts the timer. The timer will count down until reaching 0. The unit is 1ms. The value might be given by a fixed coded number or by a second variable. The defined variable and thus the elapsed time can then be evaluated. `START_TIM 10000` Will start a timer running for 10s

Example code

```
:Init
DIM StepCounter = 0
DEF_TIM_VAR t

DO

IF(StepCounter = 0) THEN
   'start the time measurement
   START_TIM 10000
   StepCounter = 1
ELSEIF (StepCounter = 1) THEN
   'timer elapsed?
   IF (t = 0) THEN
      Action()
   END IF
END IF
…
LOOP
```



So different from the micro-loop structure of the flow-chart in Figure 7 it is here possible not only to check the elapsed time but also do additional checks in each step.

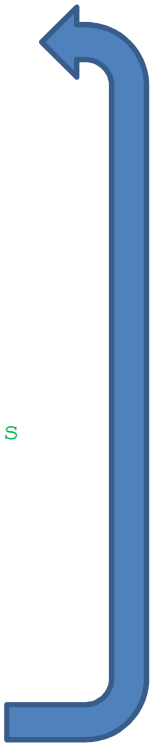
Time-measurement

The opposite approach might be the measurement of an elapsed time. This could be a transient time or any reaction time out of a supervised process. Again a timer is used, but in this case the timer starts at a value of 0 and counts the elapsed milliseconds.

Key word	Description
DEF_CYC_VAR	Defines one of the variables to be used by the timer `DEF_CYC_VAR t` Will define the variable t to be used by the timer
START_CYC	Sets the defined timer variable to 0 and starts the timer. The timer variable is incremented in the background and can be evaluated by reading the defined timer variable. The unit is 1ms. `START_CYC`
STOP_CYC	Stops the timer `STOP_CYC`

Example code

```
:Init
DIM StepCounter = 0
DEF_CYC_VAR t

DO

IF(StepCounter = 0) THEN
   'start the time measurement
   START_CYC
   StepCounter = 1
ELSEIF (StepCounter = 1) THEN
      'timer elapsed?
      '3 different actions within 1s
   IF (t > 1000) THEN
      Step1()
   ESLEIF (t > 650) THEN
      Step2()
   ESLEIF (t > 350) THEN
      Step3()
   END IF
END IF
…
LOOP
```



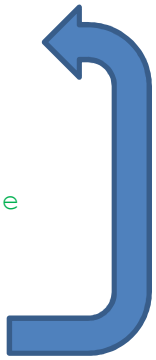
Timer variables can be evaluated within a script. Logging them via the built in logging feature of the Motion Controller is not supported directly. If you want to visualize the down- or up-counting of a timer you need to cyclically write the actual value of the selected timer variable to a second variable – which can then be logged.

Measuring the cycle time

What about the timing performance of an application. There is no built in feature to assess the cycle time of an application as there is no predefined behavior – executing loops is a recommendation only.

Measuring the cycle time of a cyclic application can be easily implemented without any special services though. Simply use a free variable and initialize it to 1. Then in each cycle multiply the variable by -1 and log the content. As the execution time of many scripts will only be a few ms it might even be necessary to use the recorder and trigger the variable crossing 0.

```
:Init
'here k is used as the trigger variable for loop time
k = 1

DO
    ' do whatever

   'invert k for logging purpose
   k = -1 * k

LOOP
```



Mixed operation of Master and local scripts

Even a combined operation of a master controller and a set of local scripts is possible. The key here is the shared access to the 26 global variables. All of them are available in object 0x3005.

So let's assume a drive shall be used for position control by a master but shall have a different set of parameters such as torque, profile parameters or even control parameters depending on the machine cycle.

This could be done by a master directly but as the master then needs to read and write these parameters, they have to be added to the process image or a dedicated SDO read/write access has to be implemented.

Alternatively you could create a local script changing the set of parameters according to a selection variable.

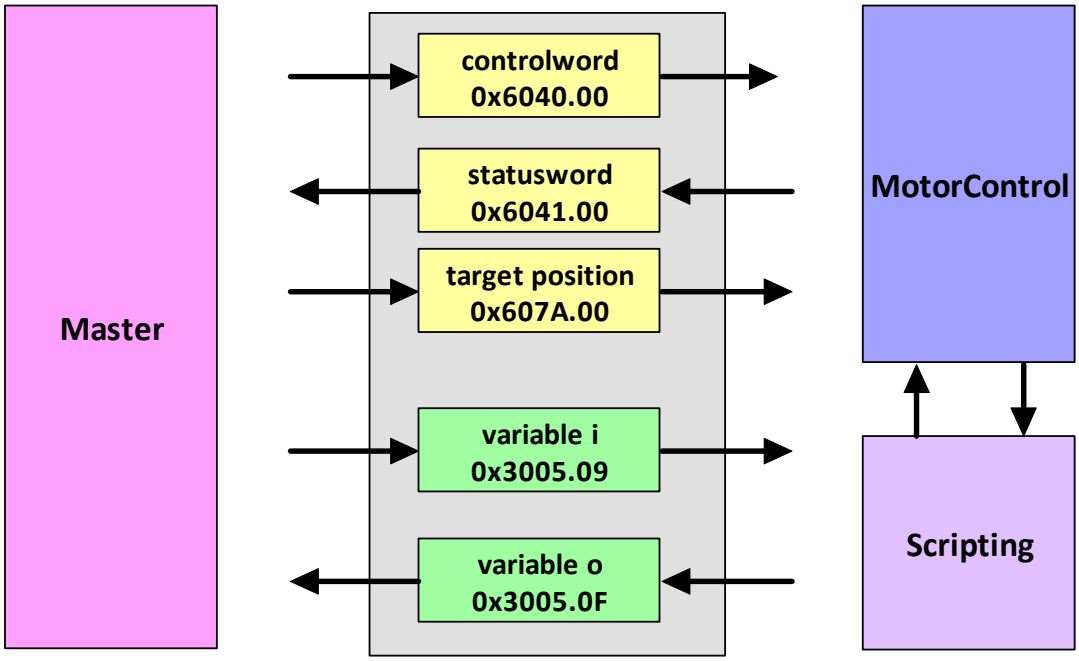


Figure 15 combination of a master PLC and local scripts

The variable here i is used by the master to start a local script. The BASIC script might use an internal step sequence to execute a sequence of the local behavior.

In such a case an output variable could signal whether such a sequence can be started, is started or is finished. Here the variable o is used as a feedback to the PLC with the values:

- o = 0: idle – no sequence is active
- o = 1: sequence is started
- o = 2: sequence is finished

Several subroutines could be stored in a single BASIC script and the contents of i could be used to select the one to be started.

Additional Resources

FAULHABER Application Notes	
App-Note 164	control a FAULHABER MC V3.0 ET out of a CODESYS environment

FAULHABER manuals at www. faulhaber.com/manuals

FAULHABER demo systems at youtube. Some of them using local scripting to control the behavior.

Rechtliche Hinweise

Urheberrechte. Alle Rechte vorbehalten. Ohne vorherige ausdrückliche schriftliche Genehmigung der Dr. Fritz Faulhaber & Co. KG darf insbesondere kein Teil dieser Application Note vervielfältigt, reproduziert, in einem Informationssystem gespeichert oder be- oder verarbeitet werden.

Gewerbliche Schutzrechte. Mit der Veröffentlichung der Application Note werden weder ausdrücklich noch konkludent Rechte an gewerblichen Schutzrechten, die mittelbar oder unmittelbar den beschriebenen Anwendungen und Funktionen der Application Note zugrunde liegen, übertragen noch Nutzungsrechte daran eingeräumt.

Kein Vertragsbestandteil; Unverbindlichkeit der Application Note. Die Application Note ist nicht Vertragsbestandteil von Verträgen, die die Dr. Fritz Faulhaber GmbH & Co. KG abschließt, soweit sich aus solchen Verträgen nicht etwas anderes ergibt. Die Application Note beschreibt unverbindlich ein mögliches Anwendungsbeispiel. Die Dr. Fritz Faulhaber GmbH & Co. KG übernimmt insbesondere keine Garantie dafür und steht insbesondere nicht dafür ein, dass die in der Application Note illustrierten Abläufe und Funktionen stets wie beschrieben aus- und durchgeführt werden können und dass die in der Application Note beschriebenen Abläufe und Funktionen in anderen Zusammenhängen und Umgebungen ohne zusätzliche Tests oder Modifikationen mit demselben Ergebnis umgesetzt werden können.

Keine Haftung. Die Dr. Fritz Faulhaber GmbH & Co. KG weist darauf hin, dass aufgrund der Unverbindlichkeit der Application Note keine Haftung für Schäden übernommen wird, die auf die Application Note zurückgehen.

Änderungen der Application Note. Änderungen der Application Note sind vorbehalten. Die jeweils aktuelle Version dieser Application Note erhalten Sie von Dr. Fritz Faulhaber GmbH & Co. KG unter der Telefonnummer +49 7031 638 688 oder per Mail von mcsupport@faulhaber.de.

Legal notices

Copyrights. All rights reserved. No part of this Application Note may be copied, reproduced, saved in an information system, altered or processed in any way without the express prior written consent of Dr. Fritz Faulhaber & Co. KG.

Industrial property rights. In publishing the Application Note Dr. Fritz Faulhaber & Co. KG does not expressly or implicitly grant any rights in industrial property rights on which the applications and functions of the Application Note described are directly or indirectly based nor does it transfer rights of use in such industrial property rights.

No part of contract; non-binding character of the Application Note. Unless otherwise stated the Application Note is not a constituent part of contracts concluded by Dr. Fritz Faulhaber & Co. KG. The Application Note is a non-binding description of a possible application. In particular Dr. Fritz Faulhaber & Co. KG does not guarantee and makes no representation that the processes and functions illustrated in the Application Note can always be executed and implemented as described and that they can be used in other contexts and environments with the same result without additional tests or modifications.

No liability. Owing to the non-binding character of the Application Note Dr. Fritz Faulhaber & Co. KG will not accept any liability for losses arising in connection with it.

Amendments to the Application Note. Dr. Fritz Faulhaber & Co. KG reserves the right to amend Application Notes. The current version of this Application Note may be obtained from Dr. Fritz Faulhaber & Co. KG by calling +49 7031 638 688 or sending an e-mail to mcsupport@faulhaber.de.