MCS2 - Getting Started with Magnetic Driven Positioners

INTRODUCTION

SmarAct's MLS product series consist of electromagnetic linear positioners that are directed towards industrial applications, lab automation and compact positioning solutions where high speed, force and nanometer precise motion need to be paired with high duty cycles and durability. The Magnetic Driver module of the MCS2 controller allows to drive three SmarAct magnetic driven positioners.
The MCS2 can be programmed by using the *SmarActCTL* library or a SCPI oriented *ASCII protocol*. (The ASCII protocol is available for controller with ethernet interface.) Detailed function and property descriptions of the application programming interface (API) can be found in the *MCS2 Programmer's Guide*. The programmer's guide mainly serves as a reference when programming your own software but it also supplies some background information for a better understanding of the overall system and explains general concepts of the MCS2.
This guide is a quick start guide to work with the MCS2 and magnetic driven SmarAct positioners. It describes the general concepts without going into the details of the programming and thus also applies when working with the Hand Control Module and existing control software.

UNPACKING AND MECHANICAL INSTALLATION

After unpacking the MCS2 controller and the positioners you should prepare all necessary connections between positioners, sensor module, controller, hand control module and PC. Figure 1 gives an overview of the structural setup of a typical MCS2 system.

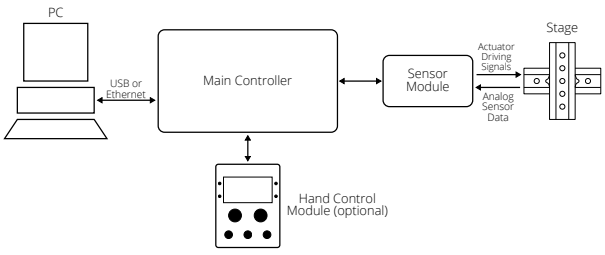

Figure 1. *Structural Setup of an MCS2 Device*

> Please refer to the *MCS2 User Manual* for more information about the hardware components and setup of the MCS2 device.

Note that positioners are equipped with a locking mechanism to avoid damages during the transport. Make sure that the transportation locks are removed as described in the positioner's assembly instructions. Mount the positioner properly to a solid base and connect the protective earth conductor according to the applicable standards in your country.

> Please refer to the *Positioner Manual* document for more information on the mechanical installation.

SETUP

The MCS2 comes with a **software installer** which installs all software and documentation needed to setup and use the MCS2 and to develop your own software. (The typical install path is *C:/SmarAct/MCS2*.)
Note for controllers with **ethernet interface** that the IP settings must be configured to match your network settings before a connection to the controller may be established. Please refer to the *MCS2 User Manual* for a detailed description of the interface configuration.
The *MCS2 Service Tool* may be used to perform the configuration of the MCS2 controller. The most important configuration tasks are described in the following sections.

Positioner Type

For correct operation each channel of the MCS2 must "know" how to calculate positions, handle the referencing, configure the control-loop, etc.
For this SmarAct controllers feature the concept of "positioner types". Every SmarAct positioner has a predefined type which is simply configured to the MCS2 controller. This concept allows a fast and easy setup of a positioning system without the need of dealing with several configuration and tuning parameters to get the system working. Optionally the MCS2 allows to modify tuning parameters, like PID gains, etc. to optimize the positioning performance according to the desired control-loop behavior and to adapt to an application perfectly.
Magnetic Driver channels utilize the **SmarAct Positioner ID System** to automatically detect the positioner type and to configure the controller with the required parameters for the position calculation, the type of referencing, the maximum allowed current and the suitable control-loop parameters. The positioner type is automatically configured to the MCS2 channel when attaching a positioner to the sensor module.

Note that the controller features hot-plugging of the positioners. Whether a positioner is connected or not may be determined by software by reading the channel state. Additionally, every change in the setup is reported by the event system.

Positioner Calibration

Even though every positioner is categorized by its type (which is configured to the channel automatically by the Positioner ID System) each individual positioner may have slightly different characteristics that require the tuning of some internal parameters for correct operation and optimal results. A calibration routine is used to adapt to these characteristics and to automatically detect parameters for an individual positioner.
When starting up with a new system or if a new positioner (with a different serial-number) is attached to a channel the **calibration routine** must be performed *once* to ensure proper operation of the positioner.
Note that a channel *must* be calibrated before it can be used for movements. Otherwise an error is generated when trying to command a movement and the channel remains in the stopped state.
The calibration routine may be started with a *MCS2 Hand Control Module*, with the *MCS2 Service Tool* or with a customer-developed software. Please refer to the *MCS2 Hand Control Manual*, *MCS2 Service Tool Manual* and *MCS2 Programmer's Guide* for more information.

OPERATION

The following section gives some recommendations and best-practice tips for the successful and safe operation of magnetic driven positioners with the MCS2 controller.

WARNING

Magnetic driven positioners are not self-locking. Disabling the amplifier or control-loop, powering off the controller or detaching the positioner from the channel removes any holding force from the positioner. Make sure not to damage any equipment when the positioner changes its position unintentionally!

Since magnetic driven positioners cannot be commanded with open-loop commands, sensor feedback is required for every movement as well as to actively hold the position. The following preconditions must be met in order to issue movement commands:

1. The positioner must be attached to the controller via a sensor module.
2. The sensor must be enabled (default setting).
3. The control-loop input must be configured to "sensor" (default setting).
4. The amplifier must be enabled (see below).
5. The phasing sequence must have finished successfully (see below).
6. The channel must be calibrated.
7. The move velocity and acceleration must be specified for the movement.

If one of the above conditions is not fulfilled an error will be generated when trying to start a movement.
The "Channel State" property may be monitored by an application to determine if a channel is calibrated, phased, referenced, the amplifier is enabled, the control-loop is active, etc.

Amplifier Enable

Each channel of a Magnetic Driver module has a built-in amplifier to provide the current to drive the positioner coils. The amplifier is disabled by default and must be explicitly enabled to perform closed-loop movements. As long as the amplifier is disabled the positioner is passive and the position is not held actively.
By factory default the amplifier is disabled on start-up or when a positioner is attached. However, the MCS2 may be configured to enable the amplifier automatically if desired. Please refer to the *MCS2 Programmer's Guide*, property *Startup Options* for more information.

Phasing

To drive brushless permanent magnet positioners the controller must know the absolute position of the slider within a magnetic period. Since the position sensor works on an incremental basis the absolute position is unknown at startup. The controller performs a special routine to establish the phasing reference. For this the coils are driven in a defined pattern while monitoring the reaction of the positioner. This sequence is known as "phasing". The phasing is started automatically when the amplifier is enabled the first time after power up of the controller.
Note that external forces or displacements must not be applied to the positioner while the sequence is running. The phasing takes some time to complete. Once the sequence has finished successfully the channel enters the *holding* state, which means that the current position of the slider is held actively using the sensor feedback.

Determining Absolute Positions

SmarAct positioners feature an optical position sensor for the closed-loop operation. Since the sensor works on an incremental basis and can only detect relative position changes, the controller has no way of knowing the absolute position of a positioner after a system

power-up. It simply assumes its starting position as the zero position.

To determine the absolute position the positioner is equipped with one or more reference marks. The referencing sequence of the controller may be used to determine the physical position in an automated fashion. For this the positioner is moved until the absolute position has been determined.

Note that the **referencing sequence** is configurable. The *start direction* of the movement as well as the *move velocity* and *acceleration* should be specified before starting the referencing. Several referencing options allow to either return to the exact position of the reference mark or to continue the movement until stopped by the control software. The reference position is determined "on-the-fly" in this case. This may be useful e.g. for mechanically coupled setups of different positioners, etc.

When starting the reference sequence the positioner will start to move in the configured start direction and look for a reference mark. If a physical end stop is encountered before finding the mark the positioner will automatically reverse its search direction at the end stop and continue to look for the reference mark in the opposite direction.

The reference sequence may be started with a *MCS2 Hand Control Module*, with the *MCS2 Service Tool* or with a customer-developed software. Please refer to the *MCS2 Hand Control Manual*, *MCS2 Service Tool Manual* and *MCS2 Programmer's Guide* for more information. The *MCS2 Programmer's Guide* also describes the reference sequence in more detail.

Endstop Detection and Software Range Limits

SmarAct positioners do not require any physical limit switches to detect the end of the travel range while moving. The MCS2 features a software-driven endstop detection. If a mechanical blockage is detected while performing a movement the channel enters the holding state to stop the movement. Furthermore the maximum output current is reduced from the intermittent current to the permitted continuous current value. This means that the holding force of the positioner is reduced from then on but with the benefit that an ongoing blockage will *not* trigger the overload detection. This would otherwise disable the control-loop and subsequently remove the holding force from the positioner. A new movement command reverts the maximum current to its intermittent value.

To prevent positioner damage by accidentally moving into an endstop with high velocity it is recommended to use the **software range limits** to define the working range. With active software range limits a positioner is automatically decelerated to zero velocity in a way that it comes to a halt on the specified limit position when commanding a movement towards a limit.

WARNING

Since magnetic driven positioners can reach very high velocities and forces, the mechanical endstops may be damaged easily when accidentally moving into an endstop with high velocity.

Startup Command Sequence

The following command sequence is recommended after starting up the controller to setup a channel for its safe operation:

1. **Enable the amplifier.** When the amplifier is enabled the channel is phased automatically and enters the *holding* state once the phasing has finished. Note that the phasing sequence induces some motion of the positioner while running.
2. **Disable the software range limits.** The limits behave similarly to a physical end stop. The referencing sequence will reverse its movement direction while looking for the reference mark if a range limit boundary is reached. If the reference mark is located outside the range limit then it will not be found. Furthermore the limits are always checked based on the current logical position scale. As long as the referencing sequence was not executed the scale does not match the physical position scale of the positioner. Therefore the limits should be deactivated for the referencing.
3. **Configure the referencing options.** For example, specify the starting direction of the search for the reference mark.
4. **Configure a moderate move velocity.** It is likely that the referencing sequence does not find the reference mark in the configured direction before reaching a mechanical endstop. To protect the positioner from damage the velocity should be limited to a value where an endstop may be hit without damaging the positioner. A max. move velocity of 10 mm/s can be used safely for linear positioners.
5. **Configure the move acceleration.** The acceleration should not be set too low for the referencing. If the distance between reference mark and endstop is smaller than the distance required to decelerate the positioner to zero velocity, then the positioner will hit the endstop and will be stopped immediately. The referencing sequence will be reported as "failed" in this case even though the reference mark was found. An acceleration of 10 m/s^2 is reasonable.
6. **Start the referencing sequence** and wait for it to finish. Polling the "Channel State" property

or listening to events may be used to determine the end of the sequence when developing your own software. If it is desired that a specific physical position matches a specific position value, then the scale may be shifted with the ”logical scale offset” or by setting the ”current position”. Please refer to the *MC2 Programmer's Guide* for more information on defining positions.

7. **Enable the software range limits.** Now that the physical position scale is known the software range limits should be configured to limit the working range. The range limit min and max settings must be specified depending on the actual user defined scale and the absolute travel range of the positioner. The travel range of your positioner can be found in the positioner's datasheet. Alternatively, the min. and max. position referenced to the user-scale may be determined easily by moving the positioner towards the two endstops with moderate velocity until an endstop is encountered. The resulting endstop positions may then be used to define the limits with sufficient tolerance to the endstops.
8. **Enable the following error detection.** This is an optional step. The following error is, at a given time, the difference between the target position and the actual position while performing movements. If a commanded trajectory cannot be followed by the positioner the movement may be aborted or the control-loop may be disabled automatically. Thereby the following error detection may be used as a safety measure to prevent a potential dangerous runaway condition of the positioner.

After these steps the positioner may be commanded to move to an **absolute position** or to move in **relative position** increments depending on the configured move mode. Note that the move velocity and acceleration must be specified for both modes. A value of zero to disable the velocity resp. acceleration control is *not* valid for Magnetic Driver channels.
When using the **trajectory streaming** function the velocity and acceleration of the positioner result from the defined trajectory which must be pre-calculated by the control software. Therefore the move velocity and acceleration properties have no meaning while performing a trajectory streaming.

Overload Protection
The Magnetic Driver module monitors the output current of each channel to detect an overload condition of the positioner. This prevents thermal overheating and potential damage of the positioners coils, isolation and permanent magnets. Every positioner type defines the limiting parameters ”continuous current”, ”maximum (intermittent) current” and ”permitted time constant”.

The **continuous current limit** specifies the highest current level the driver can apply continuously without overheating the positioner.
The **maximum (intermittent) current limit** specifies the highest current level the driver can apply for a specified **permitted time**. (Typically in the range of a few seconds.) This higher limit makes it possible to improve the performance of a movement by using a higher current for a short time, e.g. to accelerate and decelerate the positioner.
The MCS2 implements the **I2T protection** which does not require additional temperature sensors in the positioners. Whenever the control-loop is enabled the channel continuously integrates the square of the current. Because resistive heat generation is proportional to the square of the current this method gives a reasonable representation of the generated thermal load of the positioner. The difference between the squared present current and the squared continuous current is accumulated. If this sum exceeds a specified limit the overload protection triggers and the control-loop is disabled to protect the positioner. Note that this removes any holding force from the positioner.
The present load level may be read in percent with the ”Motor Load” property. This may be useful to estimate the **motor load** while performing movements *before* the overload protection triggers and disables the control-loop. In case the motor load reaches a level close to 100 % the number of movements per time, the movement acceleration and/or the mechanical load attached to the positioner should be reduced.

Custom Positioner Type Tuning
Magnetic driven positioners allow high speed movements with nanometer precision. Depending on the specific application it may be necessary to adjust the control-loop parameters to adapt to an application or to optimize the positioning performance. Furthermore, the desired trajectory, the mounting direction of the positioner and the attached mass influence the control-loop behavior. The predefined positioner types define control-loop settings which are usually tuned to almost no overshoot with low load of the positioner. If a different tuning is desired a **custom tuning** must be performed. The MCS2 controller offers this possibility by giving access to the tuning parameters.
The *MCS2 Service Tool* features a *Positioner Tuning* function to command tuning movements and to adjust the control-loop parameters. A graphical plot of the position, target, velocity and following error of the movement provides assistance while finding the best matching tuning parameters. A ”custom positioner type” with the adjusted settings may then be created and saved on the controller. Please refer to the *MCS2 Service Tool Manual* for more information and a step-by-step tuning guide.

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