Manual determination of a compensation characteristic for hydraulic valves and hydraulic axes
Siemens provides products and solutions with Industrial Security functions that support the secure operation of plants, systems, machines and networks. To protect plants, systems, machines and networks against cyber threats, it is necessary to implement (and continuously maintain) a holistic, state-of-the-art Industrial Security concept. Products and solutions from Siemens are only one part of such a concept.

It is the customer’s responsibility to prevent unauthorized access to the customer’s plants, systems, machines and networks. Systems, machines and components should only be connected with the company’s network or the Internet, when and insofar as this is required and the appropriate protective measures (for example, use of firewalls and network segmentation) have been taken.

In addition, Siemens’ recommendations regarding appropriate protective action should be followed. For more information on Industrial Security, visit http://www.siemens.com/industrialsecurity.

Siemens’ products and solutions undergo continuous development to make them even more secure. Siemens strongly recommends to carry out updates as soon as the respective updates are available and always only to use the current product versions. Use of product versions that are no longer supported, and failure to apply latest updates may increase customer’s exposure to cyber threats.

In order to always be informed about product updates, subscribe to the Siemens Industrial Security RSS Feed at http://www.siemens.com/industrialsecurity.
## Table of Contents

1  Introduction ................................................................................................................. 4  
   1.1  Motivation ............................................................................................................. 4  
   1.2  Validity .................................................................................................................. 4  
2  Basics ............................................................................................................................ 5  
   2.1  Electric axes .......................................................................................................... 5  
   2.2  Hydraulic axes ....................................................................................................... 5  
   2.3  Compensation characteristic ................................................................................. 6  
   2.4  Connecting the hydraulic axis to SIMATIC ......................................................... 7  
   2.4.1  Connecting the encoder ................................................................................... 7  
   2.4.2  Connecting the hydraulic valve ....................................................................... 8  
3  Determining the compensation characteristic ............................................................. 10  
   3.1  Prerequisite .......................................................................................................... 10  
   3.2  Parameterization of the technology object ......................................................... 10  
   3.2.1  Fundamentals on the “Axis” technology object .............................................. 10  
   3.2.2  Determining the parameter settings of the technology object ..................... 10  
   3.3  Activating the hydraulic axis in SIMATIC ......................................................... 14  
   3.4  Performing the measurement ............................................................................. 15  
   3.4.1  Preparation ....................................................................................................... 15  
   3.4.2  Measurement ................................................................................................... 15  
   3.4.3  Notes on the dynamic settings for the measurement ..................................... 16  
   3.4.4  Notes on the movement range limitation of the axis ................................... 17  
   3.4.5  Recording of measured values ....................................................................... 17  
   3.4.6  Extrapolating the 100% measured value ....................................................... 18  
   3.4.7  Determining the maximum velocity ............................................................... 19  
   3.4.8  Calculating the parameters of the compensation characteristic ................ 20  
   3.4.9  Creating the compensation characteristic ..................................................... 21  
   3.4.10  Calling the FB "LGF_NonLin" in the "MC_PostServo" OB ......................... 23  
4  Appendix ....................................................................................................................... 24  
   4.1  Measured value table ............................................................................................ 24  
   4.2  Velocity measurement .......................................................................................... 26  
   4.2.1  Velocity measurement with the technology object ....................................... 26  
   4.2.2  Velocity measurement with the technology module ..................................... 26  
   4.3  Library with general functions (LGF) ................................................................. 26  
   4.4  Links and Literature ............................................................................................. 27  
   4.5  Change documentation ....................................................................................... 27
1 Introduction

1.1 Motivation

To be able to use a hydraulic axis or a hydraulic cylinder in conjunction with a SIMATIC S7-1500 technology object, the non-linear behavior of the hydraulic axis or cylinder should be linearized. The non-linearity is usually caused by the hydraulic valve. The linearization can improve the control quality of the hydraulic axis in conjunction with the SIMATIC S7-1500 technology object. The linearization is done by means of a compensation characteristic in the SIMATIC S7-1500.

Figure 1-1 Example for the activation of a hydraulic axis

Figure 2 Example for the valve characteristic and the corresponding compensation characteristic

1.2 Validity

The approach set out here for the determination of a compensation characteristic for a hydraulic valve or axis has been developed with the following hardware components, firmware and software versions:

- TIA Portal V14
- Motion Control Library V3.0
- SIMATIC S7-1500 with firmware version V2.0
2 Basics

2.1 Electric axes

The controllers contained in the “Axis” technology object of the SIMATIC S7-1500 are designed for a linear behavior of the complete control circuit, as it is usually the case for electric axes. There is a linear relation between the output controller set point and the actual speed of the electric axis.

2.2 Hydraulic axes

This is not the case for hydraulic axes. Here, the output controller set point would not produce the desired motion speed of the hydraulic cylinder. This is due to the non-linear behavior of the hydraulic valve, via which the hydraulic cylinder is controlled. The manufacturer of the valve shows this behavior via the so-called valve characteristic.
2.3 Compensation characteristic

To be able to use a hydraulic axis in conjunction with an “Axis” technology object of the SIMATIC S7-1500, the non-linear behavior of the hydraulic valve should be linearized. This can be done by integrating a compensation characteristic into the control circuit of the technology object. For this, the “MC_PostServo” organization block (OB) can be used.

Theoretically, the compensation characteristic can be determined from the inverses of the valve characteristic, taking into account the set standardization within the control circuit. Generally, however, this method cannot be implemented so easily. The following chapters will therefore describe, how to manually determine the compensation characteristic.
2.4 Connecting the hydraulic axis to SIMATIC

In the example laid out here, an ET200SP CPU (S7-1512SP) with the corresponding ET200SP standard and technology modules will be used for the activation of a hydraulic axis.

![Figure 2-6 Hardware setup](image)

<table>
<thead>
<tr>
<th>No.</th>
<th>Module</th>
<th>Order number</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>ET200SP-CPU CPU 1512SP-1 PN</td>
<td>6ES7 512-1DK01-0AB0 Firmware: V2.0</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>DQ 8x24VDC/0.5A ST</td>
<td>6ES7 132-6BF00-0BA0 Firmware: V1.1</td>
<td>This module is not necessarily required for the activation of the hydraulic axis.</td>
</tr>
<tr>
<td>3.</td>
<td>TM PosInput 1</td>
<td>6ES7 138-6BA00-0BA0 Firmware: V1.2</td>
<td>Read-in of encoder signal of the hydraulic axis.</td>
</tr>
<tr>
<td>4.</td>
<td>AQ 2xU ST</td>
<td>6ES7 135-6FB00-0BA1 Firmware: V1.0</td>
<td>Output of analog value for the activation of the hydraulic valve of the hydraulic axis.</td>
</tr>
</tbody>
</table>

2.4.1 Connecting the encoder

With the help of an incremental encoder, the reaction of the hydraulic cylinder is captured directly at the cylinder and then read into the SIMATIC via the TM PosInput 1 technology module of the ET200SP.

In this, the technology module needs to be parameterized for use in conjunction with a Motion Control application.

- Selection of the operating mode Position input for Motion Control
- Setting the module parameters, depending on the encoder used.

Further notes on this can be found in the manual on Motion Control (\[4\]) mentioned in chapter 4.4.
Note
The operating mode “operation with technology object” is intended for the technology object “Counter” and cannot be used in conjunction with a positioning axis.

Note
Depending on the encoder type used, the technology module TM Count may also be used.

Figure 2-7 Parameterization of technology module TM Posinput 1

2.4.2 Connecting the hydraulic valve

The hydraulic valve is activated from the SIMATIC via an analog voltage output in the voltage range of -10V…+10V. For this, an AQ analog output module of the ET200SP is used.

In order to be able to run the analog output channels of the module in conjunction with a positioning axis, the I/O image of the module will be assigned to the update cycle of the “MC_Servo”.

Figure 2-8 Parameterization of the AQ analog output module

After the parameterization of the I/O addresses, the I/O tags also need to be named before they can be selected in the parameter dialog of the positioning axis.
Figure 2-9 Setting of the I/O tags of the AQ analog output module

<table>
<thead>
<tr>
<th>General</th>
<th>I/O tags</th>
<th>System constants</th>
<th>Texts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>x29</td>
<td>AQ_Channel</td>
<td></td>
</tr>
<tr>
<td>int</td>
<td>x29 (2)</td>
<td>AQ_Channel</td>
<td></td>
</tr>
<tr>
<td>Real</td>
<td>16777760</td>
<td>AQ_Channel</td>
<td></td>
</tr>
<tr>
<td>Real</td>
<td>16777761</td>
<td>AQ_Channel</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2-10 Selection of the I/O tags in the parameter dialog of the positioning axis

Note

If there are no names assigned to the I/O tags of both analog channels, they cannot be selected in the parameter dialog of the positioning axis.
3 Determining the compensation characteristic

Since the compensation characteristic usually cannot be calculated as simple, it is empirically determined by the Trace function of the TIA Portal. For this, proceed as follows:

3.1 Prerequisite

For the determination of the compensation characteristic, the following requirements have to be met:

- The hydraulic axis is connected to the SIMATIC S7-1500 by means of a technology object and can be activated.
- There is no compensation characteristic integrated or active in the control circuit of the technology object, particularly in the “MC_PostServo” organization block (OB).

3.2 Parameterization of the technology object

The parameterization of the technology object and therefore the standardization of the sizes in the control circuit is important for a correct output of the controller’s set point and need to be adjusted accordingly.

3.2.1 Fundamentals on the “Axis” technology object

The current version of the “Axis” technology object of the SIMATIC is designed for the operation of rotation axes only. If other axis types are to be connected to the technology object, then the parameters of the technology object will have to be set in such a way that the actual conditions at the axis correspond to a rotation axis configured at a technology object.

This procedure will be used in the following chapters in order to create the hydraulic axis as technology object in TIA Portal.

3.2.2 Determining the parameter settings of the technology object

The parameter settings at the technology object should be performed in such a way that, if a speed of -100% ... +100% has been specified, the controller set point output also reaches -100% ... +100%.

The following parameters briefly presented here are needed for the standardization of the controller set point output:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic parameters</td>
<td></td>
</tr>
<tr>
<td>Axis type</td>
<td>Configure in this selection, whether the axis is to perform linear or rotary motions.</td>
</tr>
</tbody>
</table>
## 3 Determining the compensation characteristic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hardware interface - Data exchange drive</strong></td>
<td></td>
</tr>
<tr>
<td>Reference speed</td>
<td>In this field, configure the reference speed of the drive in accordance with the manufacturer's specifications. The drive speed is specified as a percentage in relation to the reference speed.</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>In this field, configure the maximum speed of the drive.</td>
</tr>
<tr>
<td><strong>Advanced settings - Mechanics</strong></td>
<td></td>
</tr>
<tr>
<td>Screw pitch</td>
<td>Configure in this field, how much the load is moved, if the leadscrew rotates one revolution.</td>
</tr>
<tr>
<td>Number of motor revolutions</td>
<td>In this field, configure the number of motor revolutions (as integer).</td>
</tr>
<tr>
<td>Number of load revolutions</td>
<td>In this field, configure the number of load revolutions (as integer).</td>
</tr>
<tr>
<td><strong>Advanced settings - Limitations - Dynamic limits</strong></td>
<td></td>
</tr>
<tr>
<td>Maximum velocity</td>
<td>Configure the maximum allowed axis velocity here, taking into account the mechanics.</td>
</tr>
<tr>
<td><strong>Hardware interface - Data exchange encoder</strong></td>
<td></td>
</tr>
<tr>
<td>Measuring system</td>
<td>In the drop-down list, select, whether the measuring system is executed linearly or rotary. You can find the basic structure in the configuration window &quot;Advanced parameters &gt; Mechanics&quot;.</td>
</tr>
<tr>
<td>Increments per revolution</td>
<td>In this field, configure the number of increments that are resolved by the encoder per revolution.</td>
</tr>
</tbody>
</table>
3 Determining the compensation characteristic

Figure 3-1 Basic parameters

- Name: PositioningAxis_Hydraulic

  - Axis type:
    - Virtual axis
    - Linear
    - Rotary

  - Measuring units:
    - Measuring unit position: mm
    - Measuring unit velocity: mm/s
    - Measuring unit torque: Nm
    - Measuring unit force: N

Figure 3-2 Advanced settings - Mechanics

- Encoder:
  - Encoder mounting type: On motor shaft
  - Invert encoder direction

- Drive mechanism:
  - Invert drive direction

- Load gear:
  - Number of motor revolutions: 1
  - Number of load revolutions: 1

- Position parameters:
  - Leadscrew pitch: 1.0 mm/rev
3 Determining the compensation characteristic

As an example, specific parameter values are now to be named or determined for the individual settings in conjunction with a hydraulic axis.
Table 3-2  Example for specific parameter settings of a hydraulic axis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis type</td>
<td>--</td>
<td>Linear</td>
<td>Via this selection, the basic unit is set (here: mm).</td>
</tr>
<tr>
<td>Screw pitch</td>
<td>mm/rev</td>
<td>1.0</td>
<td>With these settings, the mechanics in the technology object do not influence the set point output.</td>
</tr>
<tr>
<td>Number of motor revolutions</td>
<td>Rev</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number of load revolutions</td>
<td>Rev</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Maximum velocity at MC_MoveVelocity</td>
<td>mm/</td>
<td>100.0</td>
<td>This value is to represent a 100% activation of the hydraulic valve in the user program.</td>
</tr>
<tr>
<td>Maximum velocity</td>
<td>mm/s</td>
<td>500.0</td>
<td>This value must be selected to be greater than or equal to the maximum velocity at MC_MoveVelocity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resulting parameter values</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference speed</td>
<td>Rpm</td>
<td>6000.0</td>
<td>The determination of these values is described in the following section.</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>Rpm</td>
<td>6000.0</td>
<td></td>
</tr>
</tbody>
</table>

The specified maximum velocity at “MC_MoveVelocity” of 100.00 mm/s, divided by the screw pitch of 1.0 mm/rev results in a motor speed of 100.0 rev/s:

Desired velocity of axis at a specified velocity of 100% at “MC_MoveVelocity”:

\[ v_{100\%} = \frac{100 \text{ mm/s}}{100\%} \]

From this, the required motor speed in consideration of the screw pitch can be deduced as follows:

\[ n_{100\%} = \frac{v_{100\%}}{\text{ScrewPitch}} = \frac{100 \text{ mm/s}}{1.0 \text{ mm/rev}} = 100 \text{ rev/s} \]

As this “speed” is supposed to represent the maximum velocity of the hydraulic axis, which is, for example, reached at an activation voltage of 10.0V of the hydraulic valve, the maximum speed at the technology object needs to be set to this value as well, using the unit rpm, however. The resulting value from 100.0 rev/s is therefore 6000.0 rpm.

Maximum speed at the technology object:

\[ j \approx 30 \cdot a \]

### 3.3 Activating the hydraulic axis in SIMATIC

The controller’s set point is output via the technology function “MC_MoveVelocity”. For this, the function needs to be switched to (speed) controlled operation before assigning the task. This is done via the “PositionControlled” input of the block, to which the “false” value needs to be assigned. This will switch off the position...
control at the “Axis” technology object, and the set point that has been specified via the “MC_MoveVelocity” technology function will be output at the controller output.

**Note**

If the standardization or the parameter settings at the technology object have been done correctly, a specified velocity at “MC_MoveVelocity” of -100% ... +100% (e.g. -100 mm/s ... +100 mm/s) can lead to a set point output of -100% ... +100% (e.g. -10V... +10V) for the hydraulic valve.

Figure 3-6  Controlled operation via the “MC_MoveVelocity” function

Stopping the axis, i.e. revoking the set point output via the controller, must be done via the “MC_Halt” technology function.

### 3.4 Performing the measurement

The determination of the compensation characteristic is done with the Trace function from the TIA Portal according to the following principle:

#### 3.4.1 Preparation

Ensure the following state:

- Check, whether the hydraulic axis can be moved from the controller (existing hydraulic pressure, valve can be activated from the controller, etc.)
- Check, that there is no valve characteristic assigned to the hydraulic axis in the controller, or that the activation signal of the hydraulic axis’ valve in the controller is not changed in the “MC_PostServo” OB.

#### 3.4.2 Measurement

Perform the measurement as follows:

- Release the configured axis in the controller via the “MC_Power” technology function.
- In TIA Portal, parameterize a trace record with the following tags of the “Positioning axis” technology object and activate the trace in the controller:
  - The set velocity “Velocity” of the axis as regulating variable of the valve in percent.
  - The actual velocity “ActualVelocity” of the hydraulic axis, as measured from the encoder signals of the axis.
3 Determining the compensation characteristic

Note

If necessary, it can be helpful to record the set point position and actual position of the hydraulic axis during the measurement as well, in order to have an absolute position reference of the measurement within the trace recording.

For the determination of the compensation characteristic, however, these measured values are not required.

- Move the axis at different velocities during controlled operation, using the “MC_MoveVelocity” technology function. Note the following:
  - Record measuring points for both, the positive and the negative movement direction of the hydraulic axis. The movement direction is determined by the sign of the velocity value at “MC_MoveVelocity”.
  - Perform more measurements within the range of smaller velocity values than within the range of higher velocities in order to receive a more precise characteristic.
  - Stop the axis each time after having performed the measurement via the “MC_Halt” technology function.
- For each specified velocity value or set point signal for the valve activation, note down the actual velocity of the hydraulic axis determined by the trace function in TIA Portal.
- After having performed the measurement, transfer the specified and measured velocity values to the compensation characteristic.

3.4.3 Notes on the dynamic settings for the measurement

Configure the dynamic settings of the hydraulic axis at the technology object for the measurement in such a way, that the axis moves at the specified or resulting constant velocity within at least half of the available movement range.

Figure 3-7 Dynamic settings for the measurement

To achieve this, you can calculate the required dynamic parameters according to the following empirical formulas:
Determining the compensation characteristic

\[ a = \frac{2 \cdot V_{\text{max}}}{x_{\text{max}}} \]

Acceleration:

\[ j \approx 30 \cdot a \]

Jerk:

Meaning of the parameters from the formulas:

- \( V_{\text{max}} \): Maximum velocity of the hydraulic axis (for axis movement with reference speed).
- \( x_{\text{max}} \): Maximum available movement range of axis for performing the measurement.

### 3.4.4 Notes on the movement range limitation of the axis

With software limit switches, you can effectively limit the movement range of the hydraulic axis. In order to use the software limit switches, however, the axis needs to be referenced before performing the measurement.

**Note**

If necessary, the use of the software limit switches may be waived and the axis may be moved up to the cylinder’s end stops. However, you should observe the maximum capacity of the mechanics.

Manually move the hydraulic axis to the center of the movement range available for the measurement. There, set the axis position to the value of 0 via the “MC_Home” technology function and symmetrically place the software limit switches into the movement range in relation to this position.

![Figure 3-8 Limitation of the movement range of the cylinder](image)

Now, the hydraulic axis can be moved between the software limit switches for the measurement. The axis will be automatically stopped at each software limit switch.

### 3.4.5 Recording of measured values

To record the measured values, you best start each trace recording with sufficient measurement time and then move the hydraulic axis with the percentage valve opening via the “MC_MoveVelocity” technology function.

After finishing the trace recording, you evaluate the recorded measured values as follows:

- As input value for the measurement, note down the percentage regulating variable for the valve opening which has been recorded in the measured value “Velocity” of the technology object of the hydraulic axis. This measured value should remain constant during the entire recording.
3 Determining the compensation characteristic

- From the measured value “ActualVelocity” of the technology object of the hydraulic axis, determine the velocity of the hydraulic axis resulting from the regulating variable according to the following criteria and enter it into the table as well:
  - The resulting velocity of the hydraulic axis should be in a steady state vibration, i.e. the acceleration phase of the axis should be completed (see Figure 3-7).
  - Should the measured value “ActualVelocity” be within a value range, the average value is to be determined from this value range (average value of the results corridor) and entered into the table as measured value.

For the recording of the measured values, the table from chapter Fehler! Verweisquelle konnte nicht gefunden werden. can be consulted.

**Note**

During the recording of the measured values, it may happen, that not all set point value steps can be recorded, e.g. due to the limitation of the movement range of the hydraulic axis.

### 3.4.6 Extrapolating the 100% measured value

If the measured value for the set point step 100% or -100% could not be determined, it needs to be extrapolated from the last two possible measured values according to the following formula (straight line equation):

General straight line equation: 
\[ f(x) = y = mx + t \]

Gradient of the straight line: 
\[ m = \frac{y_n - y_{n-1}}{x_n - x_{n-1}} \]

Shift of the straight line: 
\[ t = y_n - (mx_n) \]

Straight line equation for calculating the 100% value: 
\[ f(100) = mx + t \]
3.4.7 Determining the maximum velocity

From the determined measured values, including the possible extrapolated 100% value, the maximum of the noted velocity value now needs to be determined (in this, positive and negative direction are considered together). This maximum velocity, in return, forms the basis for the consistent parameterization of the technology object of the hydraulic axis.

The maximum value determined from the table of measured velocities represents the maximum velocity definable at MC_MoveVelocity. From this, the new parameters for reference speed and maximum speed can be calculated.

### Table 3-3 Adjusting the parameter settings of the hydraulic axis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assumed parameter values</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axis type</td>
<td>--</td>
<td>Linear</td>
<td>Via this selection, the basic unit is set (here: mm).</td>
</tr>
<tr>
<td>Screw pitch</td>
<td>mm/rev</td>
<td>1.0</td>
<td>Through these settings, the mechanics in the technology object do not influence the set point output.</td>
</tr>
<tr>
<td>Number of motor revolutions</td>
<td>Rev</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Number of load revolutions</td>
<td>Rev</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Maximum velocity at MC_MoveVelocity (v&lt;sub&gt;max&lt;/sub&gt;)</td>
<td>mm/s</td>
<td>70.0</td>
<td>This value is to represent a 100% activation of the hydraulic valve in the user program.</td>
</tr>
<tr>
<td>Maximum velocity</td>
<td>mm/s</td>
<td>500.0</td>
<td>This value must be selected to be greater than or equal to the maximum velocity at MC_MoveVelocity.</td>
</tr>
<tr>
<td><strong>Resulting parameter values</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference speed (n&lt;sub&gt;B&lt;/sub&gt;)</td>
<td>Rpm</td>
<td>4200.0</td>
<td>The determination of these values is described in the following section.</td>
</tr>
<tr>
<td>Maximum speed (n&lt;sub&gt;max&lt;/sub&gt;)</td>
<td>Rpm</td>
<td>4200.0</td>
<td></td>
</tr>
</tbody>
</table>
3 Determining the compensation characteristic

The calculation of the parameter values may follow the formula below:

Reference speed: \[ n_B = \frac{V_{\text{max}}}{t_{\text{screw}}} \cdot 60 \]

Maximum speed: \[ n_{\text{max}} = n_B \]

3.4.8 Calculating the parameters of the compensation characteristic

After the parameter values of the technology object of the hydraulic valve have been adjusted to the real conditions of the axis, the parameter values of the compensation characteristic can now be calculated from the measured values.

The set point for the hydraulic valve is output via an analog output of the controller. The output value of this analog output (which is specified without compensation characteristic directly via the controller and the corresponding standardization) now needs to be changed via the compensation characteristic.

Figure 3-10 Use of the compensation characteristic in the control circuit

The nominal range of -10 to +10\text{V} of the analog module is shown to the following value range of the output value of the analog module:

Table 3-4 Nominal range of analog output module AQ 2xU

<table>
<thead>
<tr>
<th>Output value [Decimal]</th>
<th>Output value [Percent]</th>
<th>Output value [Volt]</th>
<th>Data word [2^{16}...2^0]</th>
</tr>
</thead>
<tbody>
<tr>
<td>+27648</td>
<td>+100.0%</td>
<td>10 \text{V}</td>
<td>0110 1100 0000 0000</td>
</tr>
<tr>
<td>+1</td>
<td>+0.003617%</td>
<td>+0.03617 \text{V}</td>
<td>0000 0000 0000 0001</td>
</tr>
<tr>
<td>0</td>
<td>0 %</td>
<td>0 \text{V}</td>
<td>0000 0000 0000 0000</td>
</tr>
<tr>
<td>-1</td>
<td>-0.003617 %</td>
<td>-0.03617 \text{V}</td>
<td>1111 1111 1111 1111</td>
</tr>
<tr>
<td>-27648</td>
<td>-100.0 %</td>
<td>-10 \text{V}</td>
<td>1001 0100 0000 0000</td>
</tr>
</tbody>
</table>

The compensation characteristic precisely starts at this point and changes the analog module’s output value specified by the controller and the standardization in accordance with the measured characteristic. For this reason, the measured compensation characteristic, which is based on the axis velocity (set point value /
actual value), needs to be converted and transferred to the output value of the analog module with the following factors:

Factor for the conversion of the set point values:

\[ f_{\text{SetpointValue}} = \frac{27648}{100} = 276.48 \]

Factor for the conversion of the determined actual values:

\[ f_{\text{ActualValue}} = \frac{27648 \cdot 60}{t_{\text{Screw}} \cdot n_B} \]

\( t_{\text{Screw}} = \) Screw pitch
\( n_B = \) Reference speed

Multiply each set point value and each recorded actual value in the measurement value table with the corresponding factor.

### 3.4.9 Creating the compensation characteristic

The compensation characteristic is realized in the user program via the function block “LGF_NonLin”, which adjusts the input value on the basis of the specified characteristic. The characteristic is shown to the “LGF_NonLin” FB via a support point table with the PLC data type “LGF_typeNonLinSetpoint”.

For this, the converted measured values need to be entered into the array of the support point table for the “LGF_NonLin” FB as follows:

- Enter each converted actual value from the measured value table as “InputValue” into the data block.
- Enter each converted set point value from the measured value table as “OutputValue” into the data block.

**NOTICE**

The entries of the compensation characteristic parameters into the array for use with the “LGF_NonLin” FB need to be made in ascending order of the input values (“InputValue”). Otherwise, erroneous behavior of the “LGF_NonLin” FB may occur, resulting in adverse reactions of the hydraulic axis!

In the following chart, two compensation characteristics were created in a data block.

Figure 3-11 Exemplary presentation of the data arrays for two characteristics.
3 Determining the compensation characteristic

**Note**

If all measured values of the measured value table as shown in the chapter have been determined, an array with 35 parameter values (0..34) need to be created for the “LGF_NonLin” FB.

If fewer measured values have been determined, the array may also be dimensioned smaller. Internally, the “LGF_NonLin” FB automatically adjusts to the defined array size.

**Example**

As an example, the “NonLinSetpoints2” array in the chart above was equipped with the characteristic shown in the following chart.

*Figure 3-12  Characteristic for the exemplary “NonLinSetpoints2” array*

The entered support points result in the following straight lines, which are used by the characteristic to change the analog output value:

**General straight line equation:**

\[ f(x) = y = m \cdot x + t \]

Area: -27648.0...-11059.2 (-100%...-40%)

\[ f(x) = y = \frac{3}{2} \cdot x + 13824 \]

\[ t = f(0) = 13824 \]

\[ m = \frac{f(-27648) - t}{-27648} = \frac{27648 - 13824}{-27648} = \frac{3}{2} \]

Area: -11059.2...+11059.2 (-40%...+40%)

\[ f(x) = y = \frac{1}{4} \cdot x \]

\[ t = f(0) = 0 \]

\[ m = \frac{f(11059.2) - t}{11059.2} = \frac{2764.8 - 0}{11059.2} = \frac{1}{4} \]
3 Determining the compensation characteristic

Area:
+11059.2…+27648.0
(+40%...+100%)

\[ f(x) = y = \frac{3}{2} \cdot x - 13824 \]
\[ t = f(0) = -13824 \]
\[ m = \frac{f(27648)}{27648} - t \]
\[ = \frac{27648 - (-13824)}{27648} = \frac{3}{2} \]

Via this straight line equation, intermediate values \( f(x) \) can also be determined.

3.4.10 Calling the FB "LGF_NonLin" in the "MC_PostServo" OB

If the array is now equipped with the correct compensation characteristic values, then the “LGF_NonLin” FB can now be called up in the “MC_PostServo” OB, as exemplified in this chapter.

For this purpose, the “LGF_NonLin” picks up the analog value calculated by the position controller in this OB for the output via the analog module, then changes the value on the basis of the compensation characteristic defined by the data block and finally transmits the newly calculated value to the analog module.

In the following chart, the call up of the “LGF_NonLin” FB is shown in the programming languages FUP and SCL.

Figure 3-13 Call up of the “LGF_NonLin” FB in the programming languages FUP and SCL
### Measured value table

**Table 4-1 Measured value table**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Calculation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set point value TO &quot;Velocity&quot;</td>
<td>Actual value TO &quot;ActualVelosity&quot;</td>
<td>Set point value TO OUTPUT</td>
</tr>
<tr>
<td>-100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Use the measured value table as follows:

- Prepare the technology object used for the hydraulic axis.
- During controlled operation, enter the velocity value specified in the “set point value TO” column at “MC_MoveVelocity” and record the reaction of the hydraulic axis via Trace. If the movement range of the hydraulic axis is limited and you cannot measure all indicated set point values, start with the set point value 0 in the table and work towards the possible maximum value in both, positive and negative direction.
- In the “Actual value TO” column, note down the average value from the actual hydraulic axis velocity as determined by the Trace.
- If the velocity values for the set point values -100 and +100 cannot be measured, interpolate these values by means of the following formulas.

**General straight line equation:**
\[ f(x) = y = mx + t \]

**Gradient of the straight line:**
\[ m = \frac{y_n - y_{n-1}}{x_n - x_{n-1}} \]

**Shift of the straight line:**
\[ t = y_n - (m \cdot x_n) \]

**Straight line equation for calculating the 100% value:**
\[ f(100) = m \cdot 100 + t \]

- Now, newly standardize the technology object on the basis of the measurement

**Reference speed:**
\[ n_B = \frac{V_{\text{max}}}{t_{\text{Screw}}} \cdot 60 \]

**From the recorded measured values, calculate the values for the compensation characteristic now by using the following formulas and then enter them into the “Calculation” column. In this, transfer “Set point value TO” to “Set point value TO” and “Actual value TO” to “Actual value TO”.

**Factor for the conversion of the set point values:**
\[ f_{\text{SetpValue}} = \frac{27648}{100} = 27.648 \]

**Factor for the conversion of the determined actual values:**
\[ f_{\text{ActualValue}} = \frac{27648 \cdot 60}{t_{\text{Screw}} \cdot n_B} = \text{Screw pitch} \]

**Then transfer the calculated values into the array of the support points of the characteristic in the user program. In this, enter the value from the “INPUT”**
column as “InputValue” and the value from the “OUTPUT” column as “OutputValue” and make sure that the “InputValue” values are sorted in ascending order.

4.2 Velocity measurement

4.2.1 Velocity measurement with the technology object

The velocity of the axis is made available in the technology object (TO) via the ActualVelocity parameter. The velocity displayed here is calculated by the technology object from the received position data (increments of the encoder). For this purpose, the technology object counts the increments received from one servo cycle and calculates the resulting velocity from it.

Particularly in the case of smaller velocities and low resolution encoders, the resulting velocity value may be somewhat unstable.

4.2.2 Velocity measurement with the technology module

The TM Count technology module also captures the current velocity of the axis. For this purpose, the module measures the time between two encoder pulses. That way, the current velocity of the axis can be determined fairly precisely for smaller velocities as well.

The velocity determined by the technology module is transferred as DWORD to the controller in the telegram 83 of the encoder and via the NIST_B parameter. In this parameter, the velocity is expressed as a percentage in relation to the parameterized reference speed. The value 4000 0000 HEX expresses the 100% value of the velocity. By means of the reference speed of the axis or the encoder, the screw pitch and the measuring gearbox, the actual value of the current velocity can be determined from this.

Example calculation

<table>
<thead>
<tr>
<th>NIST_B from the telegram</th>
<th>146_{HEX} = 326_{DEZ}</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% value of telegram</td>
<td>4000 0000_{HEX} = 16384_{DEZ}</td>
</tr>
<tr>
<td>Set Reference speed at TM Count</td>
<td>3000 Rpm = 50 rev/s</td>
</tr>
<tr>
<td>Screw pitch</td>
<td>10 mm/rev</td>
</tr>
<tr>
<td>Measuring gearbox</td>
<td>1:1 (i.e. without influence)</td>
</tr>
<tr>
<td>Calculated reference speed</td>
<td>50 rev/s · 10 mm/rev = 500 mm/s</td>
</tr>
<tr>
<td>Current velocity from telegram</td>
<td>(326 / 16384) · 500 mm/s = 9.949 mm/s</td>
</tr>
</tbody>
</table>

4.3 Library with general functions (LGF)

The library “LGF (Library of general functions)” provides complementary functions for the STEP 7 (TIA Portal) instructions and contains, inter alia, the “LGF_NonLin” function block for the realization of a characteristic function.
The library can be downloaded via the Siemens Industry Online Support (SIOS) under the link mentioned in chapter 4.4.

### 4.4 Links and Literature

Table 4-1

<table>
<thead>
<tr>
<th>No.</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Siemens Industry Online Support</td>
</tr>
<tr>
<td>2</td>
<td>Link to the entry page of the application example</td>
</tr>
<tr>
<td>3</td>
<td>Application example</td>
</tr>
<tr>
<td></td>
<td>Library with general functions (LGF) for STEP 7 (TIA Portal) and S7-1200 / S7-1500</td>
</tr>
<tr>
<td>4</td>
<td>Manual</td>
</tr>
</tbody>
</table>

### 4.5 Change documentation

Table 2-3

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Modifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1.0</td>
<td>05/2017</td>
<td>First version</td>
</tr>
</tbody>
</table>