Application: Compax3 with M21 option

Force control with Compax3 and ETH cylinder

(and other actuators)

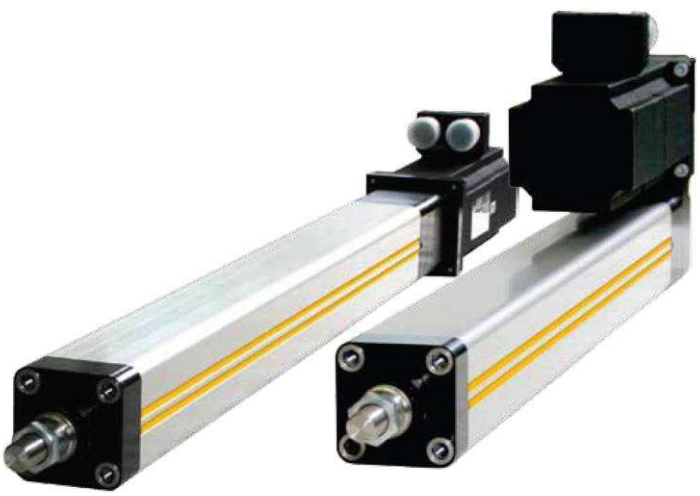

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Table of Contents

1 General

1.1 Changes

Date	Contents
16.05.14 kw	V101: First version
26.05.14 kw	V102: modification

1.2 Overview

This manual describes configuration and T30/T40 IEC program of a force control application example with ETH cylinders. Of course any other cylinder or linear mechanical system can also be used as actuator.

1.3 Hardware Requirements

For connection of a force sensor with C3S, controller hardware needs M21-option:
CTP17/01 IFM28 = M21 option with 3 analog current and 3 analog voltage inputs.

If standard hardware without M21 option is used, medium impedance inputs may require scaling adjustment due to voltage drop.

Attention: Template wizard T44 does not work with standard CTP17/01 without M21 option hardware!
Attention: With M21 no other Mxx option (HEDA, I/Os) is possible.

1.4 Ordering information

Order Code

Devices: Compax3

	1	2	3		4	5	6	7	8
Order example	C3	S	025	V2	F10	I10	T10	M00	

Example for M21 option:
C3 Sxx Vx **F10/11** Ixx T30/40 **M21**
C3 Sxx Vx **F12** Ixx T30/40 **M21**

1.5 Software Requirements

Firmware: R09-63 (standard firmware)

Tool: R09_62 or higher
C3Mgr Template T44 V8 stored in user data folder …\APPL\

IEC: FORCE_SPEED_T44_8.PRO (just as an example and to export force function block)

IEC C3Targets: T30 V3.13, T40 V3.13 or higher

Application description and program example are delivered on C3-DVD. They can also be downloaded from Parker EME knowledgebase.

Attention: Don't confuse Template T44 with a non existing technology function T44. Template T44 is a specific configuration template which operates with T30 or T40 standard device.

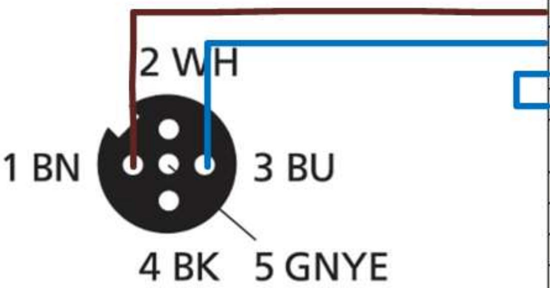
1.6 Boundary conditions

Force control with ETH cylinders need a special hardware option for C3 as well as configuration template T44 in combination with two special IEC program modules. Any application needs more functionality than only force control, therefore IEC program in general has to be adapted by customer. C3 has to be of type T30 or T40. **Thus customer needs some knowledge in IEC programming with structured text.**

1.7 Hardware connections

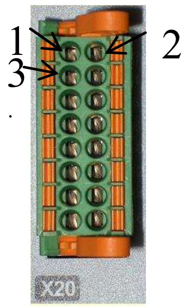
1.7.1 Wiring for analog input in case of M21 option

X20 current inputs (0…. 20mA)

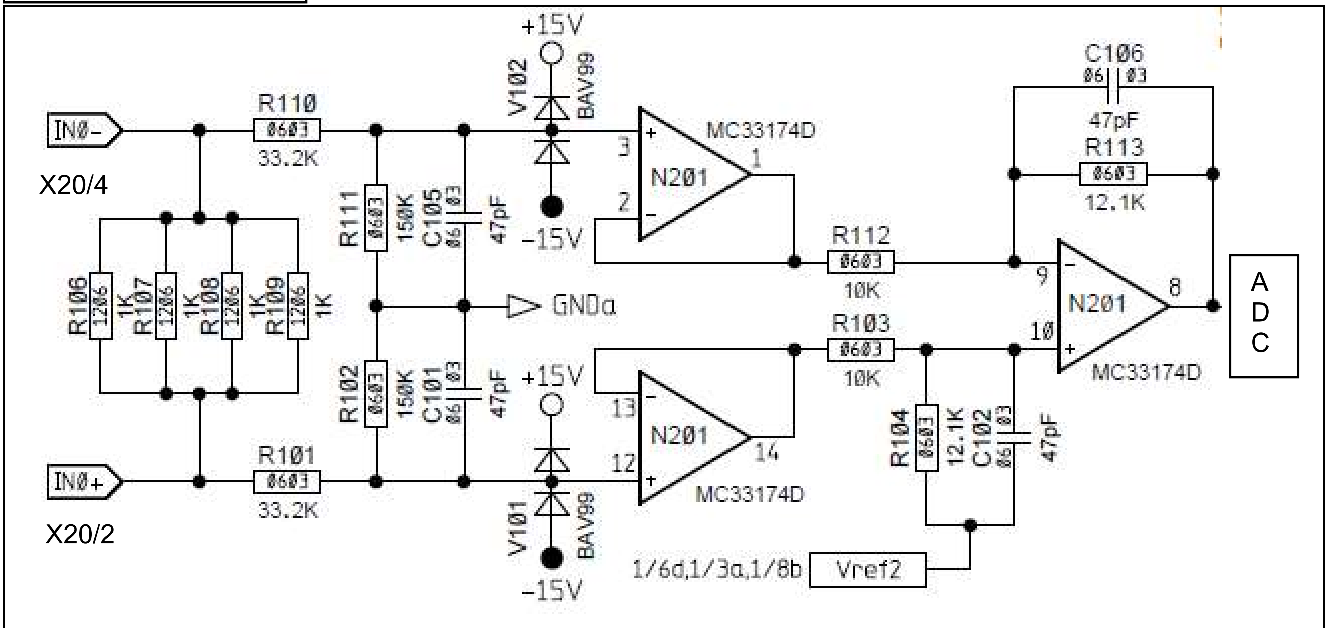


X20: Stromeingänge (0 ... 20 mA)

Pin	Name	Funktion	Interner Eingangskanal
1	+24Vout	Sensorversorgung 0 (Ausgang)	AI0
2	in0+	Stromeingang 0 + (0 ... 20 mA)	AI0
3	GND	Sensorversorgung 0 (Ausgang)	AI0
4	in0-	Stromeingang 0 - (0 ... 20 mA)	AI0
5	+24Vout	Sensorversorgung 1 (Ausgang) 24 VDC out	AI1
6	in1+	Stromeingang 1 + (0 ... 20 mA)	AI1
7	GND	Sensorversorgung 1 (Ausgang)	AI1
8	in1-	Stromeingang 1 - (0 ... 20 mA)	AI1
9	+24Vout	Sensorversorgung 2 (Ausgang)	AI2
10	in2+	Stromeingang 2 + (0 ... 20 mA)	AI2
11	GND	Sensorversorgung 2 (Ausgang)	AI2
12	in2-	Stromeingang 2 - (0 ... 20 mA)	AI2
13	+24Vin	Sensorversorgung Eingang 24 VDC in	
14	GND in	Sensorversorgung Eingang	
15	Shield	Schirmanbindung	
16	Shield	Schirmanbindung	



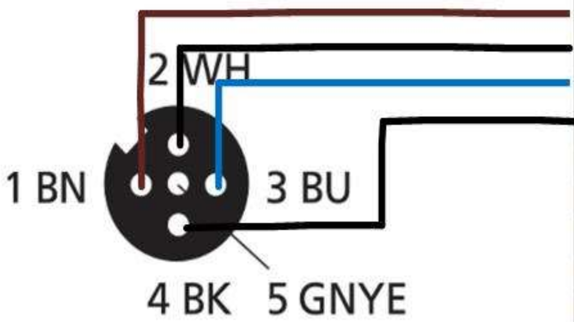
X20 Connector



Wiring of analog interfaces (X20, AI0-AI2)

Note: X20 (only current inputs) needs external 24VDC for sensor power supply(X20 Pin13/14).
Due to improved accuracy no calibration needed.

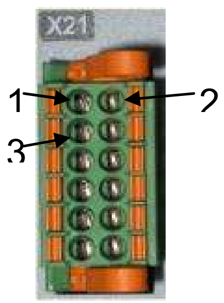
X21 voltage inputs (-10V…. +10V)



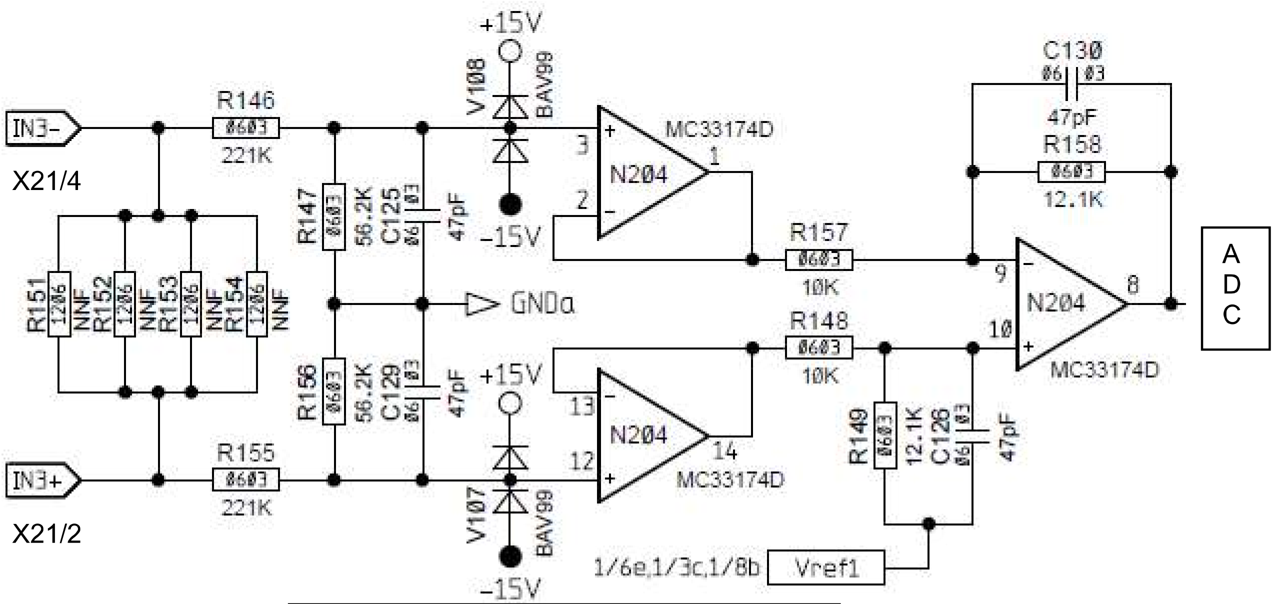
X21: Spannungseingänge (-10 V... +10 V)

Pin	Name	Funktion	Interner Eingangskanal
1	+24Vout	Sensorversorgung 3 (Ausgang)	AI0
2	in3 +	Spannungseingang 3 + (-10... +10 V)	
3	GND	Sensorversorgung 3 (Ausgang)	
4	in3 -	Spannungseingang 3 - (-10... +10 V)	
5	24 VDC out	Sensorversorgung 4 (Ausgang)	AI1
6	in4 +	Spannungseingang 4 + (-10... +10 V)	
7	GND	Sensorversorgung 4 (Ausgang)	
8	in4 -	Spannungseingang 4 - (-10... +10 V)	
9	24 VDC out	Sensorversorgung 5 (Ausgang)	AI2
10	in5 +	Spannungseingang 5 + (-10... +10 V)	
11	GND	Sensorversorgung 5 (Ausgang)	
12	in5 -	Spannungseingang 5 - (-10... +10 V)	

Eingangswiderstand 554 kΩ



X21 Connector



Wiring of analog interfaces (X21, AI0-AI2)

Note: X21 (voltage inputs) doesn't need external 24VDC input for sensor power supply.

2 Device calibration & scaling

Note: Due to improved accuracy no calibration on M21 inputs needed.

C3 hardware calibration will be necessary if a high absolute precision is required as mentioned in the ETH catalogue (page 32) for joint head with integrated force sensor.

Technical Data

Joint head with integrated force sensor ETH...										
	Unit	ETH032			ETH050			ETH080		
		M05	M10	M16	M05	M10	M20	M05	M10	M32
Accuracy	[%]	0.2								
Material	-	Stainless steel								
Protection class	-	IP67								
Calibration to	[kN]	±3.7	±3.7	±2.4	±9.3	±7.0	±4.4	±17.8	±25.1	±10.6
Accuracy	[N]	14.8	14.8	9.6	37.2	28.0	17.6	71.2	100.4	42.4
Part No.	-	0111.916		0111.917	0121.916	0121.917	0121.918	0131.916	0131.917	0131.918

Only possible with cylinder rod end "M" (external thread)

Without any calibration C3 will have a small offset error and a gain error.

Typical classes of precision based on a force sensor with precision of 0.2% from measuring range (also see catalogue of ETH, Art# 190-550017N5):

Type of precision	Force control without hardware calibration	Force control with hardware calibration	Torque control without force sensor (motor Kt)
Absolute precision	+/- 2%	0.2% of measuring range	10%
Repeatability	0.1%	0.1%	2% *

*Temperature-sensitive

Device calibration is done in two steps.
Step1: Customer calibration of analog current input hardware or analog input scaling in the field via optimization window.
Step2: Sensor interface scaling by configuration (force control wizard and T44 template scripting)

2.1 Example: Sensor ETH080_M05

Force sensor is calibrated by manufacturer for a measuring range of -17.8kN … +17.8kN;
Absolute Precision = 0.002*35.6kN = 71.2N

Compared with this, absolute precision for force sensor mounting in rear clevis is limited to 1% of measuring range.

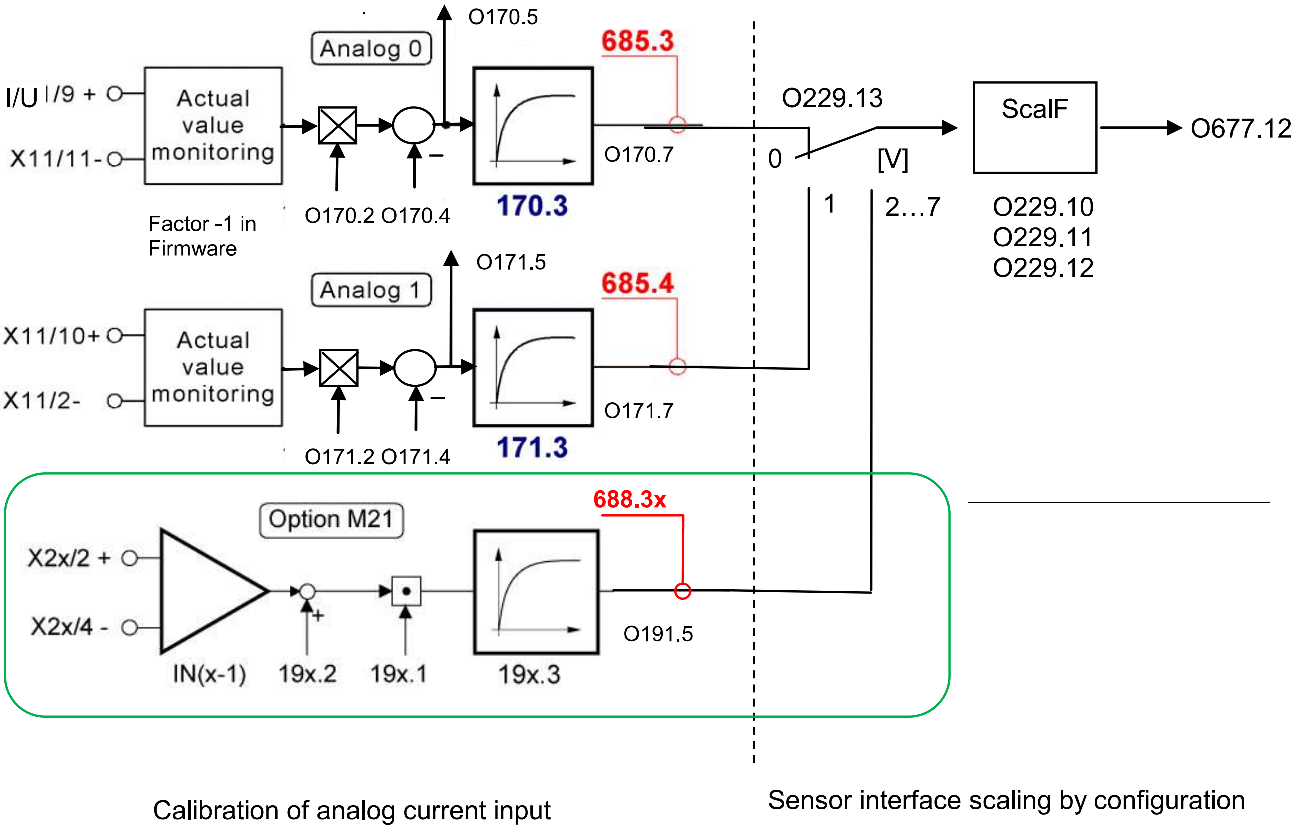
Technical Data

Rear clevis with force sensor for ETH...										
	Unit	ETH032			ETH050			ETH080		
		M05	M10	M16	M05	M10	M20	M05	M10	M32
Accuracy	[%]	1								
Material	-	Stainless steel								
Protection class	-	IP67								
Measuring range	[kN]	±3.7	±3.7	±2.4	±9.3	±7.0	±4.4	±17.8	±25.1	±10.6
Accuracy	[N]	74.0	74.0	48.0	186.0	140.0	88.0	356.0	502.0	212.0
Part No.	-	0112.034-01		0112.034-02	0122.034-01	0122.034-02	0122.034-03	0132.034-01	0132.034-02	0132.034-03

Only for parallel configuration and cylinders with "F" mounting option (mounting thread on the cylinder body)

2.2 Structure of analog input scaling

Please note that this structure isn't correct concerning the sequence of offset and gain correction. Also there is an inversion factor -1 in firmware. Real structure looks as follows:



Note: set analog input filter O19x.3 to smallest possible values if signal noise must be reduced AND force control loop must have maximum bandwidth. Please refer also to controller tuning directives.

2.3 Customer calibration for C3 M21 option (current inputs)

Force sensors are calibrated by manufacturer. Thus force/current-factor is as precise as possible. Compax3 analog inputs in force control hardware option M21 are designed for 0…20mA or 4…20mA. They have to be calibrated by customer during application set-up.

Note: Use of Template T44 >=V8 recommended!
Calibration process for C3 devices with M21 option gives configuration values for analog input 0, 1 and 2. These values are stored remanently in objects O19x.1 and O19x.2 today.
During configuration upload from drive they are stored in C3P project. Before configuration download, these objects are removed from object download list to ensure that values cannot be overwritten by C3Mgr.
Standard configuration without template T44 overwrites scaling object with actual C3Mgr release. From a later release on calibration parameters will be stored in EEPROM.

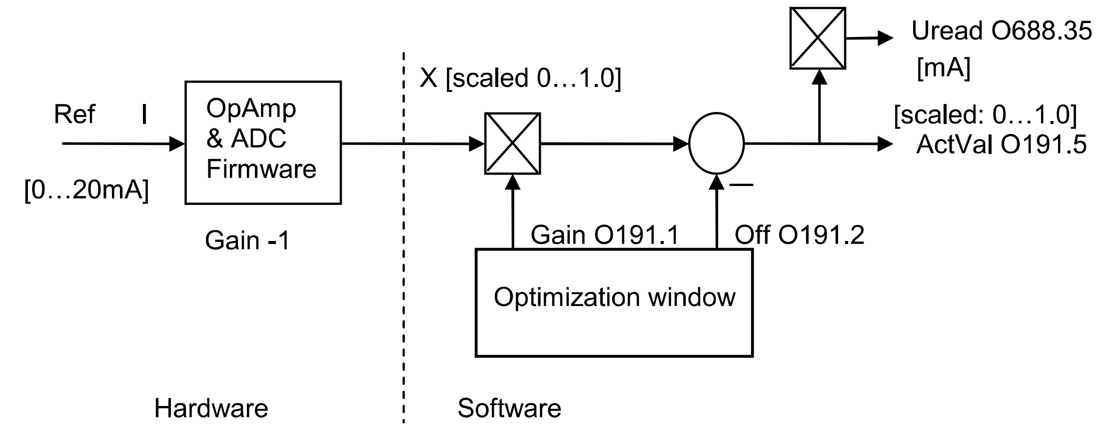
Note: For the calibration calculation Excel table "Scaling of analog current inputs.xlsx" can be used.

2.4 Analog current input scaling in the field by customer

The scaling of analog current inputs can be done using a two point method.

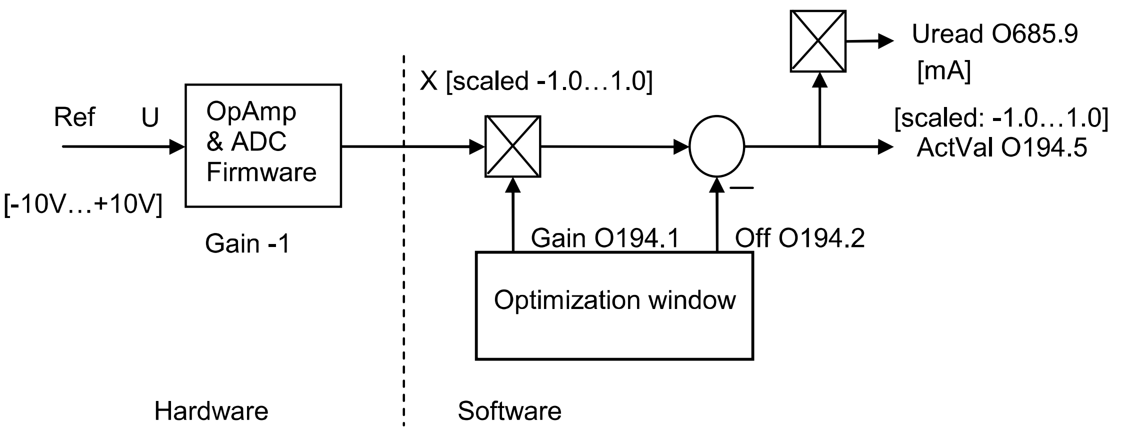
Ref current In0/In1/In2	ActVal O688.3x	Comment
I1 (e.g. 4mA)	I1	First measuring point nearby zero
I2 (e.g. 20mA)	I2	Second measuring point nearby maximum swing

2.4.1 Analog current input 0 signal flow



Same structure for analog input 1 and 2.

2.4.2 Analog voltage input 3 signal flow



Same structure for analog input 4 and 5.

2.4.3 Analog input quick tuning (example with input 0)

1. To check and quick tune analog input 0 please set "GAIN" O191.1 to -1 and start this procedure with offset O191.2 = zero.
2. Look at filtered "VALUE" O191.5 with analog input filter set to maximum: O191.3 = 7000%.
3. Calculate offset as Off = GAIN * (REF – VALUE)

Under **no load condition** = no force applied to sensor O191.5 should show following values:

	Actual Value "REF" at filtered O191.5 at no load after tuning		
Measuring region:	only tension	only pressure	tension / pressure
Current IF: 0…20mA	0mA → 0	0mA → 0	10mA → 0
Current IF: 4…20mA	**4mA → 0.2**	**4mA → 0.2**	**12mA → 0.6**

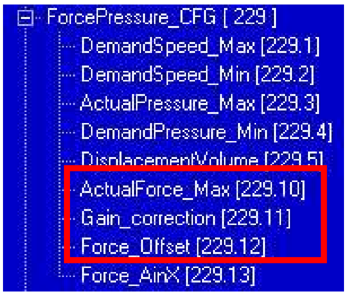
Use same procedure for analog input 1 and 2 if necessary.

Note: Don't forget to reduce analog input filter after fine tuning to minimum possible values to avoid time delay in closed loop force control.

2.5 Sensor interface scaling

This scaling is based on sensor type / measuring range:
Type 1: only tension
Type 2: only pressure
Type 3: tension / pressure

There are 3 Objects in the Firmware which are used by C3Mgr for the interface scaling.



Obj 229.10 maximum Force at full signal (10V/20mA)
Obj 229.11 corrects the Gain Error (default value = 1.0)
Obj 229.12 corrects the Offset in [N]

Note: User is not allowed to manipulate these Objects due to the fact that they are calculated by C3Mgr wizard and overwritten during configuration download.

2.5.1 Measuring region overview

Analog current input M21:

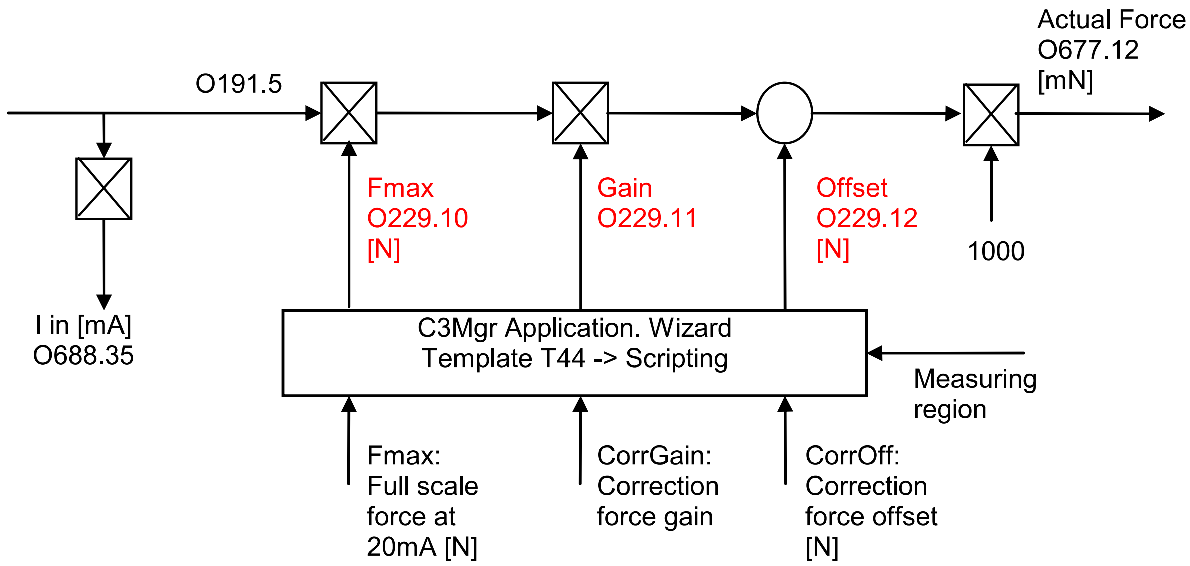
Type	1 (only tension)	2 (only pressure)	3 (tension / pressure)
Current signal	0 / 4 … 20mA		
Force range	0 … -Fmax	0 … +Fmax	-Fmax … +Fmax
Internal value	0 / 0.2 … 1.0		
Force point 1			
Force value 1	0N	0N	-Fmax
Analog value 1	0mA / 4mA		
Force point 2			

Force value 2	-Fmax	+Fmax	+Fmax
Analog value 2	20mA		

Analog voltage input M21:

Type	1 (only tension)	2 (only pressure)	3 (tension / pressure)
External signal	-1.0 … 1.0		
Force range	0 … -Fmax	0 … +Fmax	-Fmax … +Fmax
Internal voltage	-10V … 10V / 0 … 10V		
Force point 1			
Force value 1	0N	0N	-Fmax
Analog value 1	-10 / 0V		
Force point 2			
Force value 2	-Fmax	+Fmax	+Fmax
Analog value 2	10V		

2.5.2 Force scaling & correction signal flow (M21/input0)



Note: Objects O229.10 …12 calculated by C3Mgr; not allowed for user access)

Interface	0 … 20mA Msr(1)) 1	4 … 20mA Msr(1) = 2	0 … 10V Msr(1) = 3	**-10…10V** **Not yet implemented in T44 8!**
resulting current / voltage O688.3x/ O685.x	0mA … 20mA	4mA … 20mA	0V … 10V	**-10V … 10V**
Internal scaled value 19x.5	0 … 1.0	0.2 … 1.0	0 … 1.0	-1.0 … 1.0
Measuring region:				
Only tension Msr(3) = 1	Gain' = -1 Offset' = 0	Gain' = -1.25 Offset' = 0.25*Fmax	Gain' = -1 Offset' = 0	Not relevant
Only pressure Msr(3) = 2	Gain' = 1 Offset' = 0	Gain' = 1.25 Offset' = -0.25*Fmax	Gain' = 1 Offset' = 0	Not relevant
Tension / pressure Msr(3) = 3	Gain' = 1/0.5=2 Offset' = -Fmax	Gain' = 2.5 Offset' = -1.5*Fmax	Gain' = 1/0.5 = 2 Offset' = -Fmax	Gain' = 1 Offset' = 0

And in general:
Gain = Gain' * CorrGain
Offset = Offset' * Sign(CorrGain) + CorrOff

This table and correction algorithm is implemented in template T44.

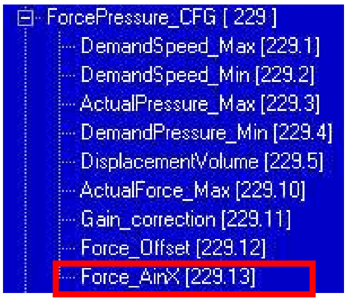
2.5.3 Additional force correction

Additional force correction may be necessary due to sensor mounting. If actor movement with positive speed yields to decreasing or negative force values, this would cause positive instead of negative feedback in closed force control loop and therefore produce instability (speed would increase beyond limits).
In this case actual force value must be inverted by setting “Correction force gain” to -1.0.

3 Analog Interface for actual force value

3.1 Selection of analog input channel

Object 229.13 defines the interface / analog input for the force sensor.

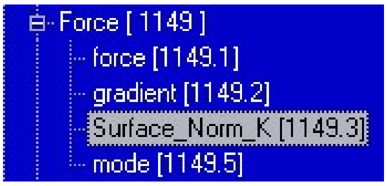


o. 229.13	ForcePressure_CFG_Force_AinX	Activating O190.1/O190.2
0	Analog input 0 (X11)	
1	Analog input 1 (X11)	
2	M21 Option / Analog current input 0 (X20)	2#xxx1
3	M21 Option / Analog current input 1 (X20)	2#xx1x
4	M21 Option / Analog current input 2 (X20)	2#x1xx
5	M21 Option / Analog voltage input 3 (X21)	2#xxx1
6	M21 Option / Analog voltage input 4 (X21)	2#xx1x
7	M21 Option / Analog voltage input 5 (X21)	2#x1xx

Note: Objects O229.13 and 190.1/2 set by C3Mgr; not allowed for user access)

3.2 Fix settings

Object 1149.3 must be set fix to **10**! (done in IEC program, module init_defaults)

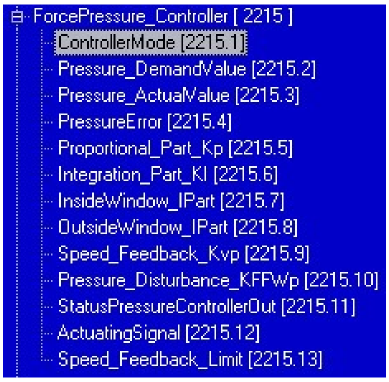


This object is necessary for calculations between pressure and force!
Internally control structure is always calculated in pressure units.

Object 2215.1 is set by IEC program depending on force control mode. This object activates Force closed loop control.

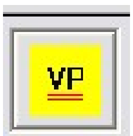
Controller structure:

Standard force control:	force-current cascade
Advanced force control:	force-speed-current cascade

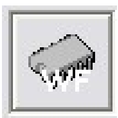


From template T44 V5 @ Firmware 2010R09_42 on it is possible to select between standard force control (mode = 3: force-current cascade) and advanced force control (mode = 4: force-speed-current cascade).

⇨ VP necessary

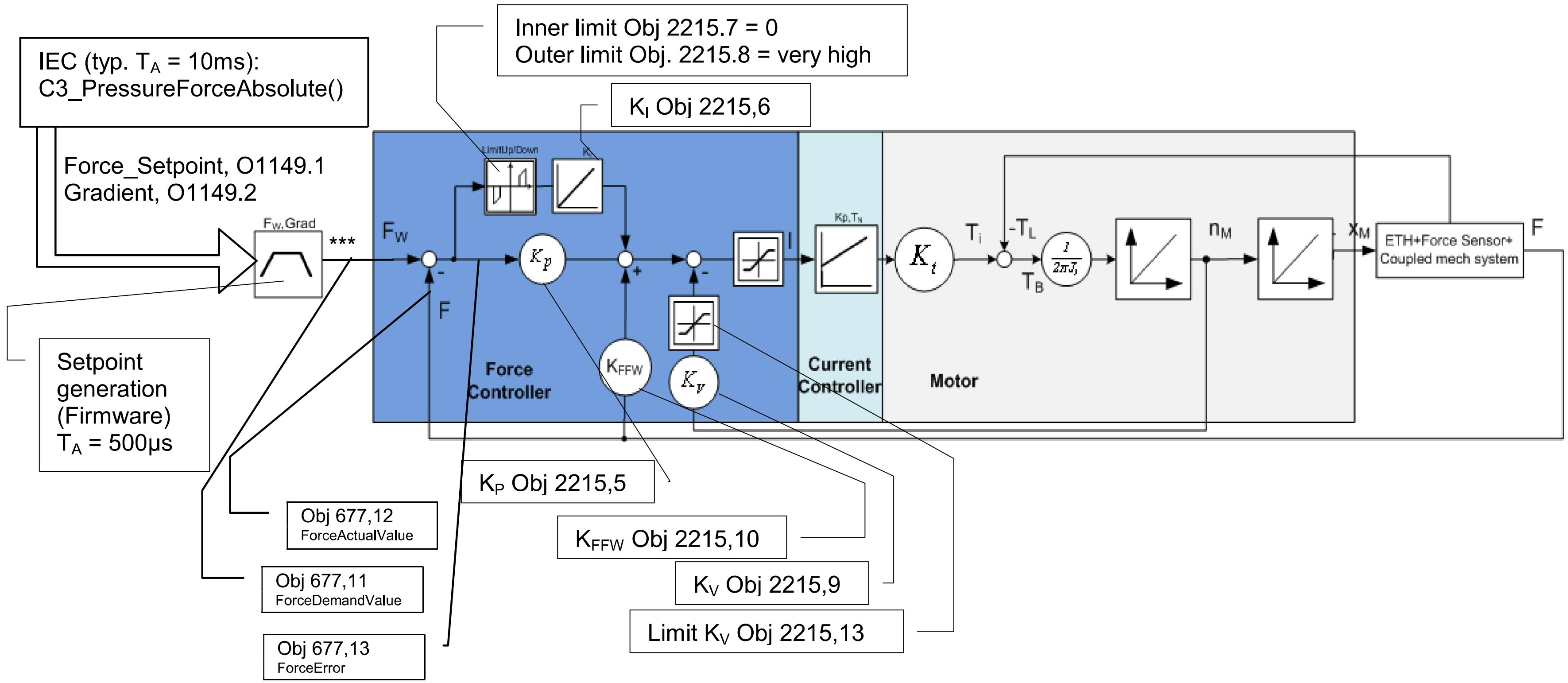


⇨ Write Flash



4 Force Closed Loop Control

4.1 Standard controller structure (Force-Current cascade)

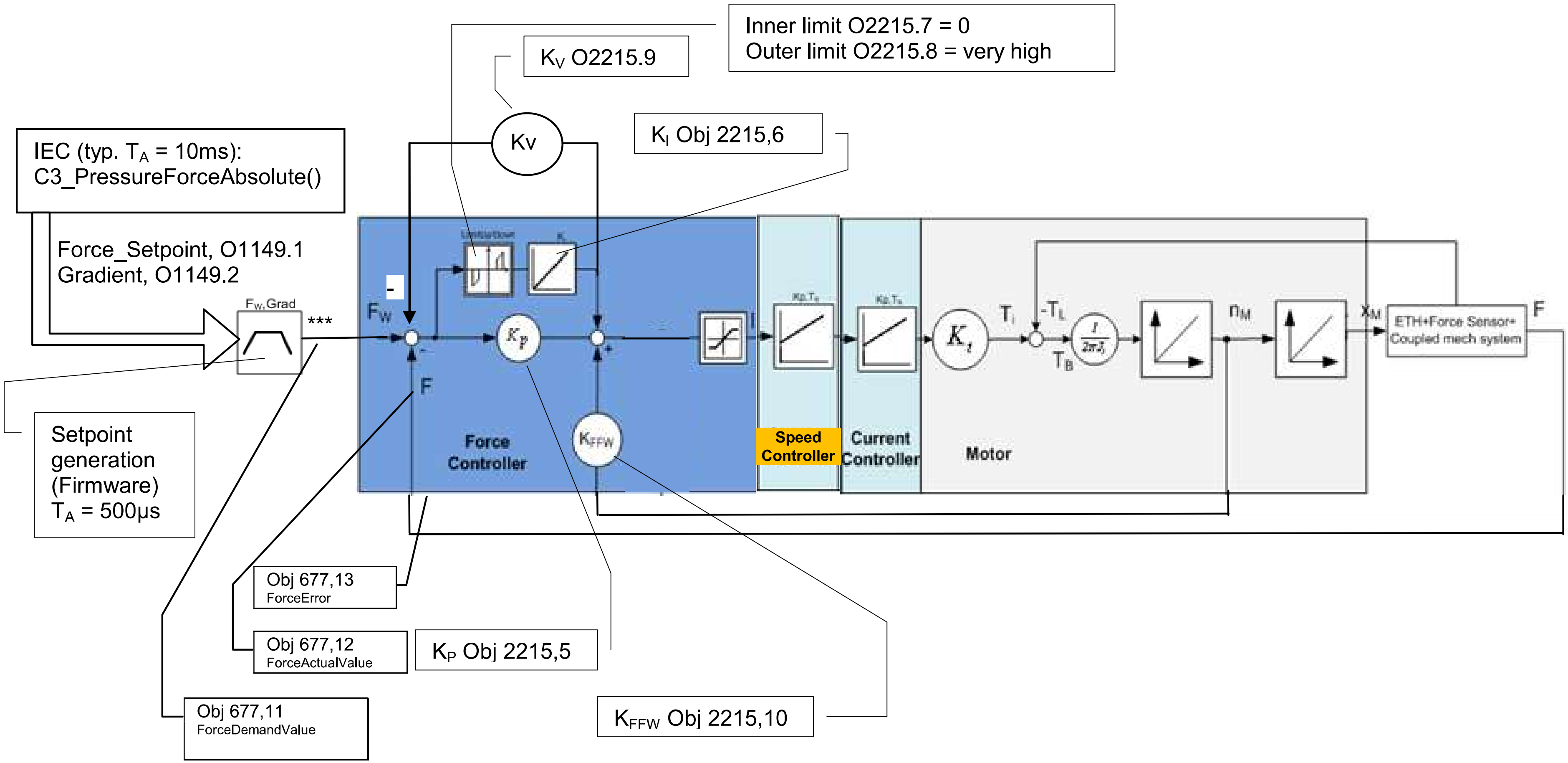


Please note the different sampling periods T_A:

IEC program:	typically 10ms. Sampling period Sampling period of force controller is 125µs.
Set point generator SG1:	500µs (***: there is actually no fine interpolation between SG1 and force controller)
Force controller:	125µs

The unit of controller coefficients is % rated motor current per N.
Example: K_P=1 %/N ➔ means, that 1% of rated current will be set if 1N Error occurs!
Note: Limit Kv Obj. 2215,13 MUST be set to 100% if Kv Obj. 2215,9 is in use.

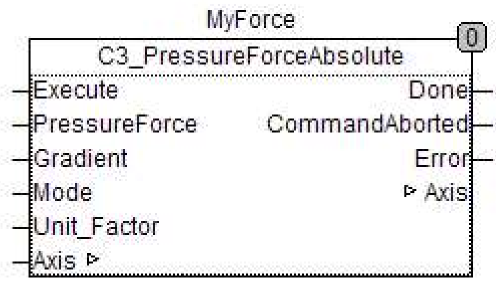
4.2 Advanced controller structure (Force-Speed-Current cascade) >= R09-40



Note: KFFW O2215.10, does not make sense in this structure and has to be set to zero! Only KP O2215.5 (acts as damping) and KI O2215.6 (acts as inertia) should be used. Kv O2215.9 has been added in R09-40 to realize some damping of integral part.
Note: Any D-Part is not available in force controller despite of existing objects O2215.15 … .17.

5 Setpoint Generation

The Function Block ***C3_PressureForceAbsolute()*** activates with Execute positive edge Force Closed Loop Control.



Inputs:

Execute:	activates Force Closed Loop Controller	BOOL-value
PressureForce:	Force Setpoint	DINT-value
Gradient:	Force Gradient	DINT-value
Mode:	Setpoint Update Mode:	
	<>3: with positive Edge of Execute input	
	=3: continuously (but with slow IEC sampling rate)	
Unit_Factor:	1.0 for Setpoint/Gradient in [N]	
	0.001 for Setpoint/Gradient in [mN]	
	1000 for Setpoint/Gradient in [kN]	

Please note: Gradient is changed only once when FB is executed, also in mode 3.

If the Setpoint is achieved, the Done output will be set to TRUE.

At Start of the Force Controller first time, the alignment to the current force value will be done.

To switch over to the positioning control either MC_Stop() or MC_MoveAbsolute/Relative() function blocks can be used.

Attention!

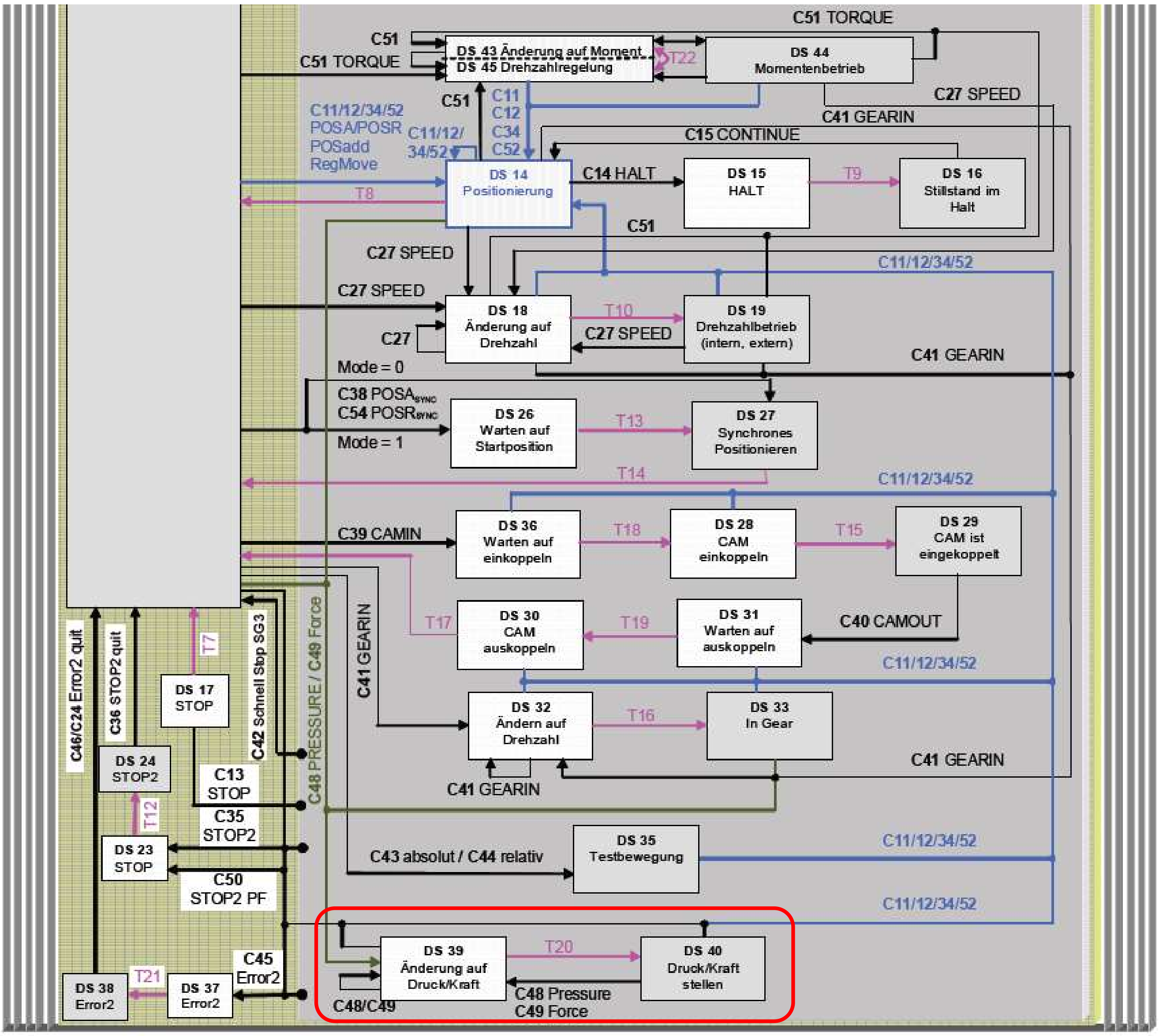
At positive edge on Execute input the Force Controller will be activated and position/speed controller deactivated without checking of the actual force. So at load force=0 in the opposite direction to the movement the motor will accelerate.
The speed monitoring and other requirements have to be implemented in the IEC Program outside of this function block.

5.1 Workaround for fast reference values from fieldbus

If a short response time is required please proceed as follows:

- ➔ Select C3Plus.Force_mode O1149.5 = 3
- ➔ Set C3Plus.Force_gradient to the maximum possible value O1149.2 = 8388607
- ➔ Copy reference value cyclically to C3Plus.Force_force O1149.1 in fast IEC task Task_500()

5.2 State diagram



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Command C49 is used to start force control.
From device state DS 40 it is possible to change into dynamic positioning with command C11 (POSA) or C12 (POSR).
From device state DS 13 “standstill” or 14 “positioning” it is possible to change directly into force control with command C49.

6 IEC Program with Force control functions

6.1 Basic IEC functionality

Axis is moved from any starting position against mechanical blocking with relative positioning and configurable force limit. When force exceeds threshold, positioning mode is switched into force control mode.
During force control mode a specific speed limit is monitored. In case of violation of speed limit error reaction "Speed too high" is released.
When force mode is stopped axis returns to homing position.

This application example also includes standard operation functionality like homing and jogging.

6.2 Force reference and ramp

Signal	Description
Force_Ref	Force reference value via C3Array.Col01_Row08
Gradient	Slope of changes in force reference in N/s, C3Array.Col03_Row09; set to maximum 8388607 if force reference should be copied directly to force controller

6.3 Current control

Signal	Description
Bandwidth	Standard set to 50%
Damping	Standard set to 100%

6.4 Fast PI controller with optional speed feedback in firmware

Signal	Description
P_part	REAL: KP O2215.5
I_part	REAL: KI O2215.6
InsideWindow	REAL: Inside window I-part O2215.7 = 0 typ.
OutsideWindow	REAL: Outside window I-part O2215.8 = 100000 typ.
V_feedback	REAL: Speed feed forward O2215.9
KFFW	REAL: Feed forward O2215.10
Limit_V	REAL: Speed feedback limit O2215.13
Controller Mode	INT: O2215.1 = 3: Force-Current cascade = 4: Force-Speed-Current cascade

Note: when controller mode is set to 4, speed feed forward makes no sense and has to be kept at zero. Only P- and I-Part are to be used.

6.5 "Speed too high" Error Reaction

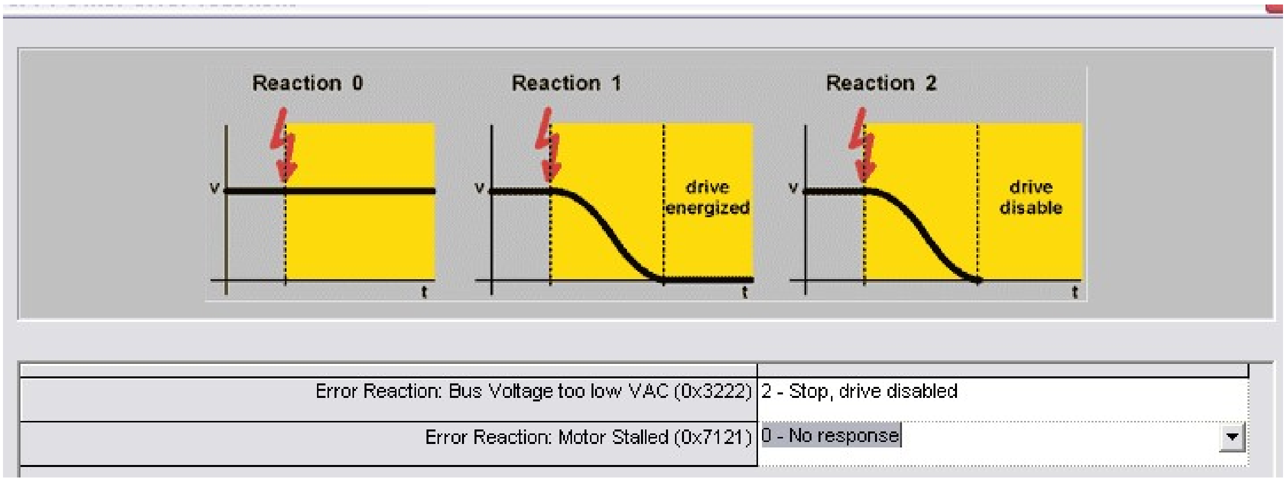
Signal	Description
SpeedLim	In force control mode a specific speed limit is valid. If speed exceeds limit "SpeedLim" in [%] of rated speed, error bit for standard reaction "Speed too high" is set.

C3.StatusSpeed_ActualScaled O681.12 is compared with SpeedLim. If exceeding, Bit 9 in C3Plus.ErrorActual_Word1 O500.1 is set.

7 C3Mgr Configuration

The Actuator has to be configured as usual.

However the Error Reaction for the Error ***"Motor Stalled"*** must be disabled.

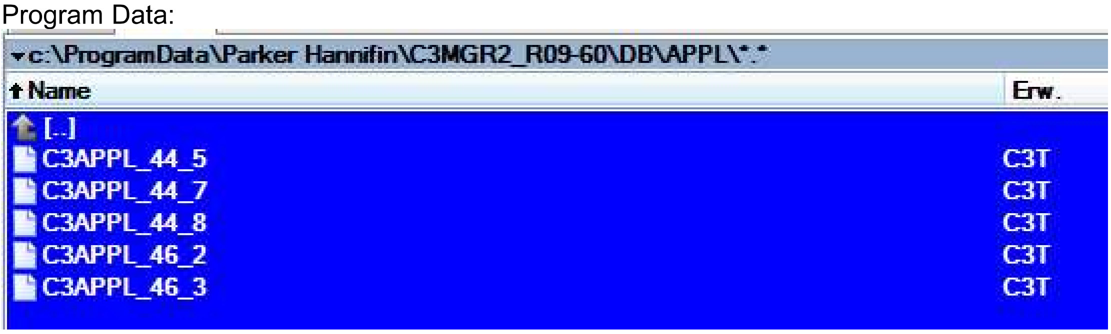


7.1 Template implementation

With stand-alone C3Mgr (Windows7):

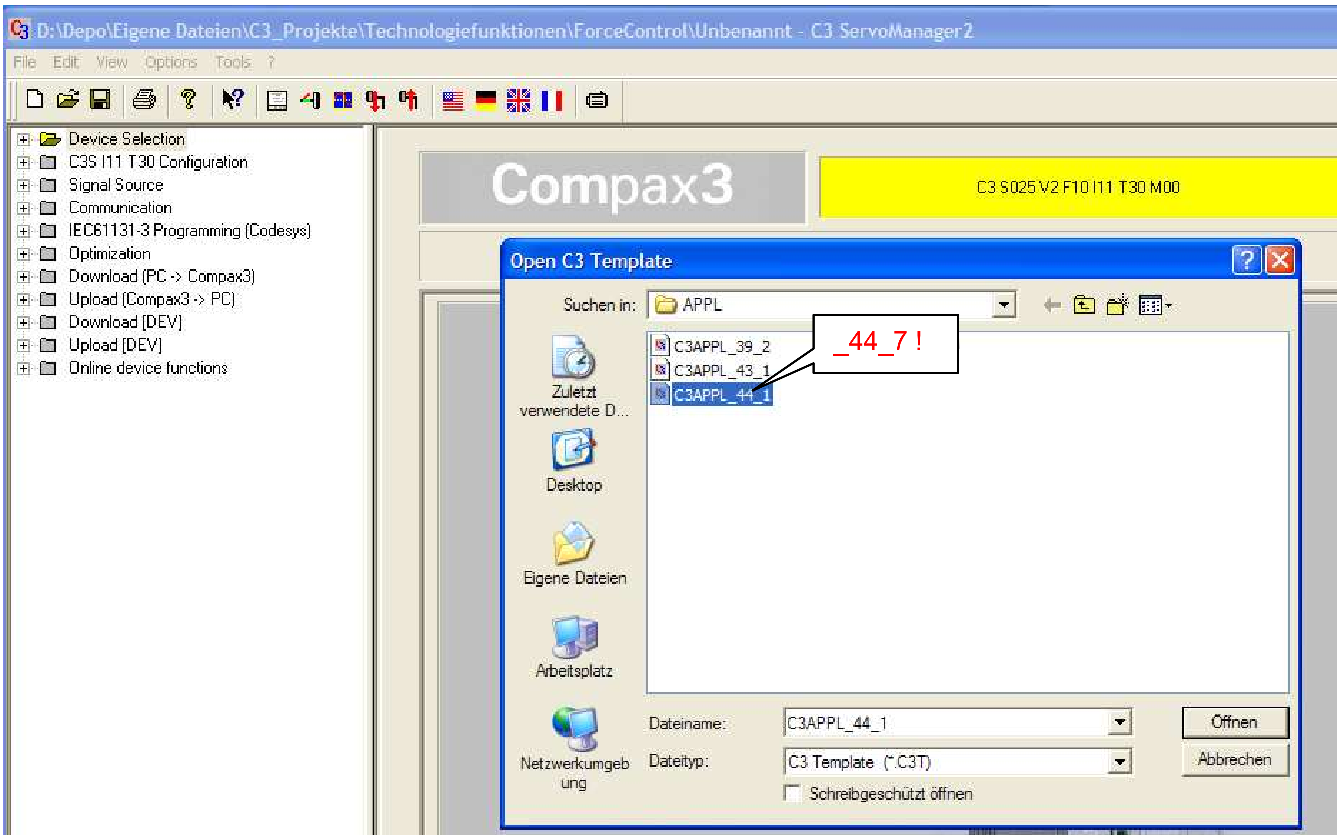
- ➔ R09-30 and following: Copy Template C3APPL_44_x (x = 8 or higher version) into user data of C3Mgr, folder c:\ProgramData\Parker Hannifin\C3MGR2_R09-60\DB\APPL\
- ➔ Open C3 Template C3APPL_44_x

Program Data:



Note: Normally the folder: c:\ProgramData…. is hidden. So change the settings to show hidden files:

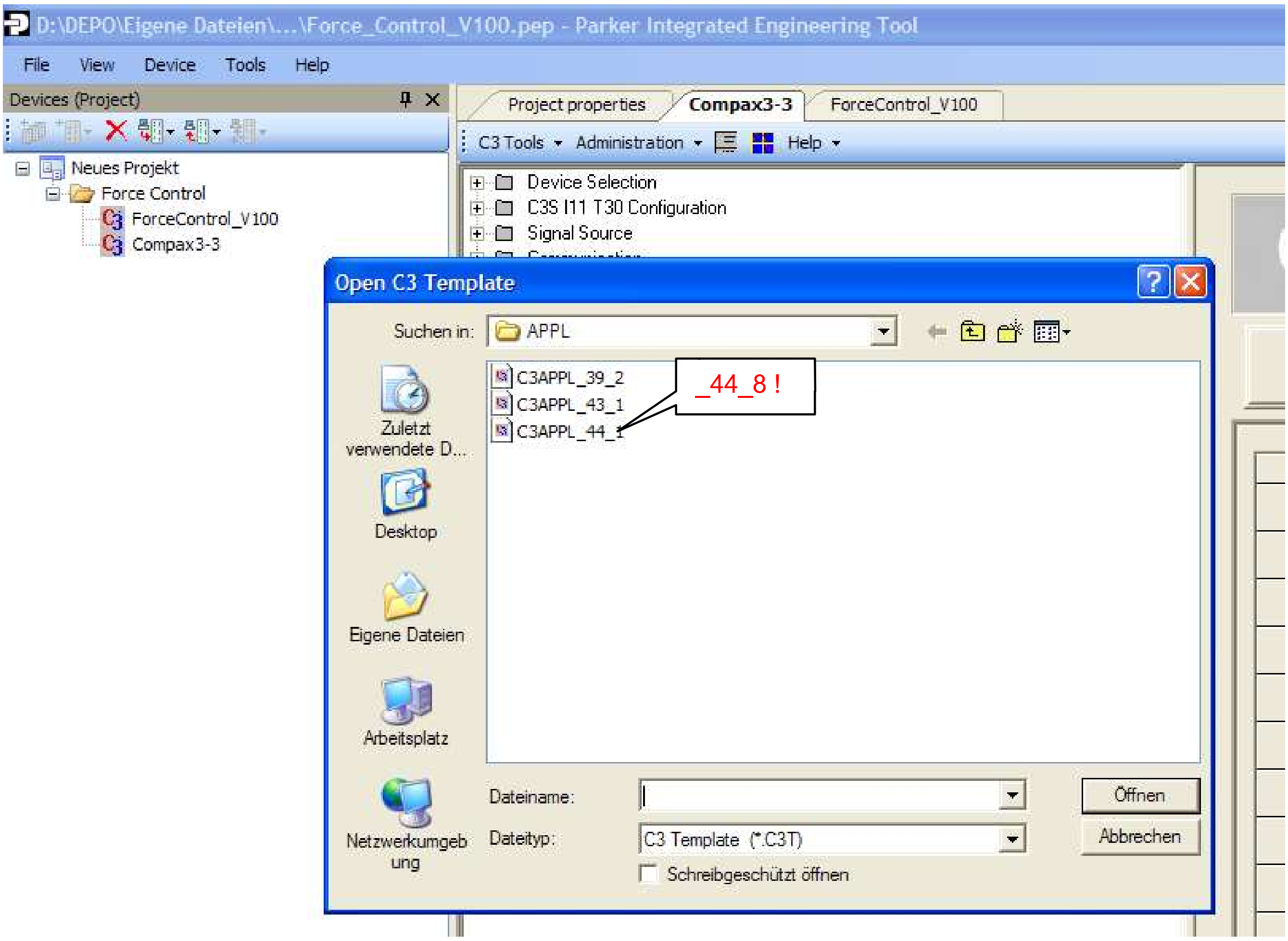
1. Open Folder Options by clicking the **Start** button, clicking **Control Panel**, clicking **Appearance and Personalization**, and then clicking **Folder Options**.
2. Click the **View** tab.
3. Under **Advanced settings**, click **Show hidden files, folders, and drives**, and then click **OK**.



Enter standard ETH configuration (or any other mechanic) and make application specific inputs.

With PIET:

- ➔ Insert new axis Compax3 and open it
- ➔ Select menu “Device” -> Open C3 Template -> C3APPL_44_x



7.2 Template T44 V3

Application specific Parameters (number = internal msr-variable):

1. ComboBox Force Sensor Type (0..20mA, 4..20mA, 0…10V)
2. ComboBox Force Sensor Channel (Analog In 0, Analog In 1)
3. ComboBox Force Mode (only tension / only pressure / tension&pressure)
4. Force Sensor nominal Force [N] at 20mA (-> O229.10)
5. Force Gain correction (-> O229.11)
6. Force Offset [N] (-> O229.12)
7. Force Gradient [N/s]
8. Force Threshold [N]
9. Speed limit [% of rated speed] in force control mode

Template version must be >=3.

7.3 Template T44 V4

Application specific Parameters (number = internal msr-variable):

10. ComboBox Controller structure (Force-Current or Force-Speed-Current cascade)

With V4 sign of Correction Force Gain isn't considered correctly in internal force offset O229.12.

This behavior is corrected in template T44 V5

7.4 Template T44 V5

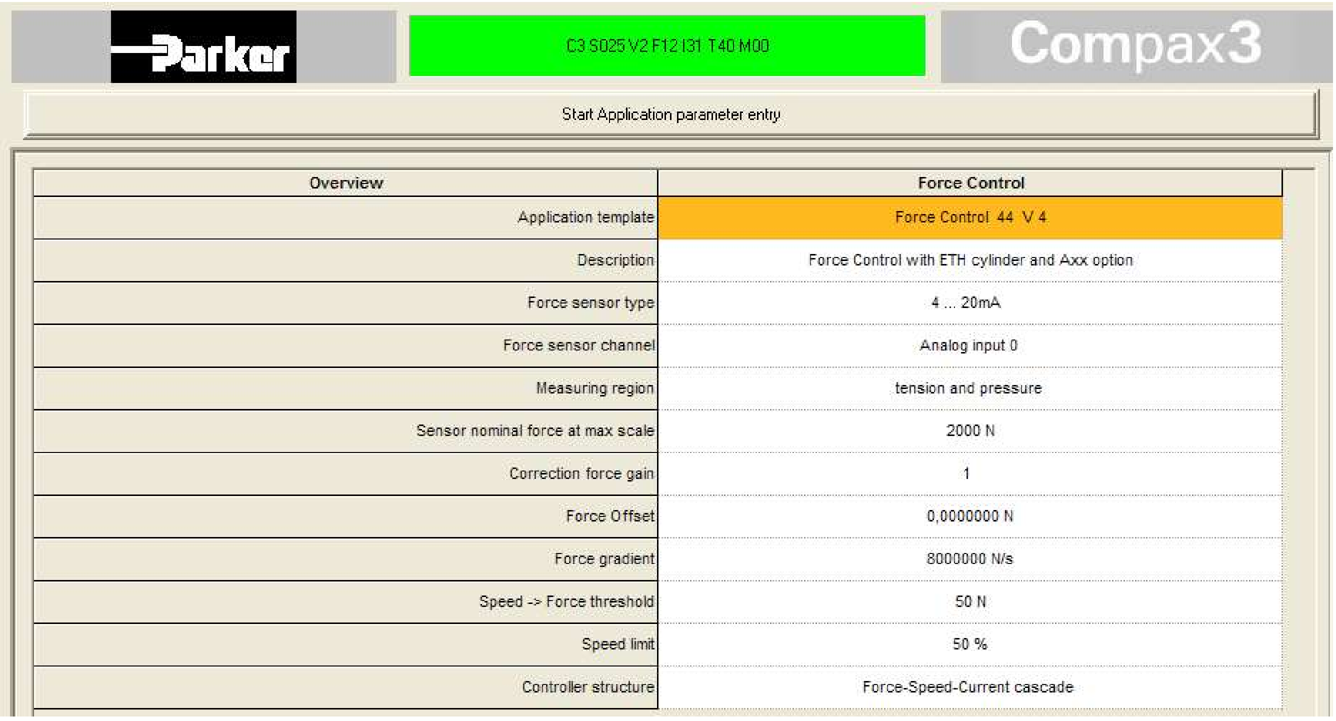


Figure: Application Wizard

7.5 Template T44 V6

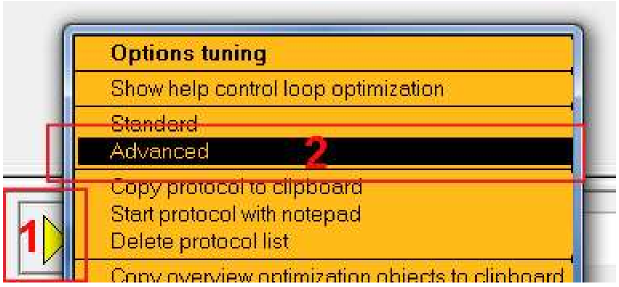
Due to an incompatibility between ETH wizard and application wizard a new template version has been created in December 2013. Wizard outlook is the same as before.
Please note: This template needs C3Mgr R09-61 or higher.
C3Mgr R09-40 can be used with T44 V5 if ETH wizard is not used.

7.6 Template T44 V7/8

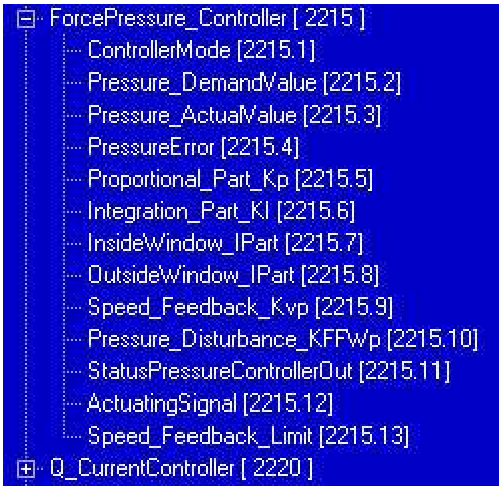
Extended ComboBox “Force sensor chanel” in ForceControl wizard for M21- option.
Please note: This template needs C3Mgr R09-62 or higher and also C3Firmware R09-62 or higher.

7.7 Controller tuning

Controller tuning isn't available in standard optimization wizard. The "advanced mode" should be activated. Or it can be also done via Object Tree.



Overview optimization objects		
Optimization object	**Value**	**Unit**
Torque/Force control		
P term [2215.5]	0.1199999	%/pres
I term [2215.6]	0.0400000	%/(s pres)
I term inner window control deviation [2215.7]	1.0000000	pres
I term outer window control deviation [2215.8]	50.0000000	pres
Torque/Force (actual value) injection in controller gain [2215.10]	0.0000000	%
Speed (actual value) injection | Damping gain [2215.9]	0.0000000	%s/unit
Speed limit for speed (actual value) injection [2215.13]	100	%



Setting to activate object tree, which has to be made in file [C3mgr installation path…]\ c:\ProgramData\Parker Hannifin\C3MGR2_R09-60\DB\compax3.ini:

```
…
[opt]
OTREE=1
…
```

Or activate directly in optimization window

8 IEC program

T30 Standard IEC program with PI controller in firmware can be imported from “Application example ETB” project.

8.1 Module overview

Application is programmed in ST language. The program is divided into several function blocs:

Function blocks	language	Task
PLC_PRG()	ST	Main program with standard functionality
C3_Pressure ForceAbsolute	ST	Slow parts (mode, ramp, initialization) of force control
Task_500()	ST	Fast copy of reference value parallel to IEC program

8.2 Main program PLC_PRG()

Main program is running with 5-10ms sampling period. It provides some standard functions like MC_Power, MC_Reset, MC_Home and C3_Jog.

8.3 Homing procedure

Homing is based on standard configuration.

8.4 C3_PressureForceAbsolute

```
(*  ****************************************************************************************
   **  Function block:     C3_PressureForceAbsolute                                          **
   **  Author:             Waldemar Warkentin                                                **
   **  Version:            2.0                                                               **
   **                                                                                        **
   **  Description:        This function block exerts continuously a force with a specified Force Setpoint using  **
   **                      a defined ramp (Gradient), and sets the Done output if theSetpoint Force is           **
   **                      reached. Can be used in continuous motion and for discrete motion. During             **
   **                       the TorqueControl mode the position controller is disabled                          **
   **                                                                                        **
   **  Attention!:         No speed overmonitoring! Speed overmonitoring must be done by                         **
   **                      application PLC PGM!                                                                  **
   *****************************************************************************************)
```

To apply firmware scaling to a wide range of force values (few mN … kN) it is necessary to set an appropriate unit factor in declaration of this function blok:

Unit_Factor:	REAL:=	1.0	-> Setpoint in N,
		0.001	-> Setpoint in mN
		1000	-> Setpoint in kN

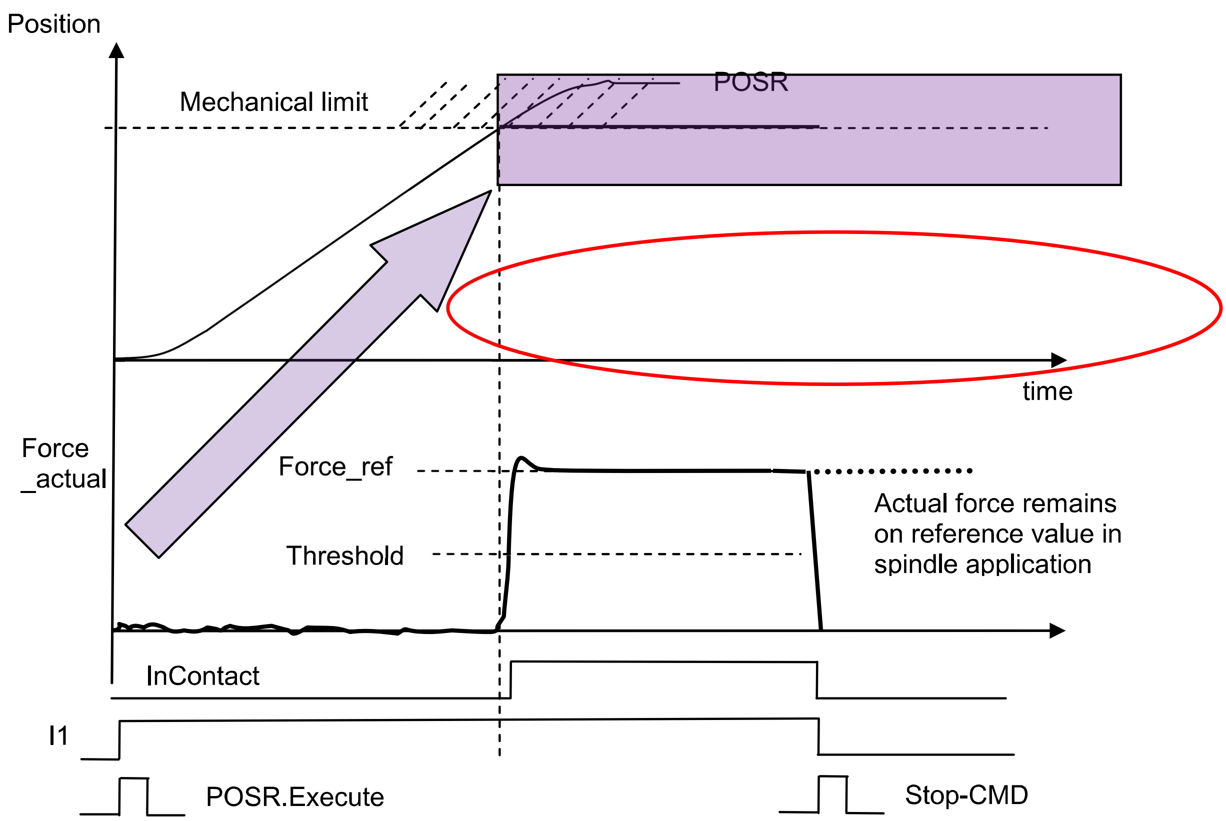
8.5 Task_500()

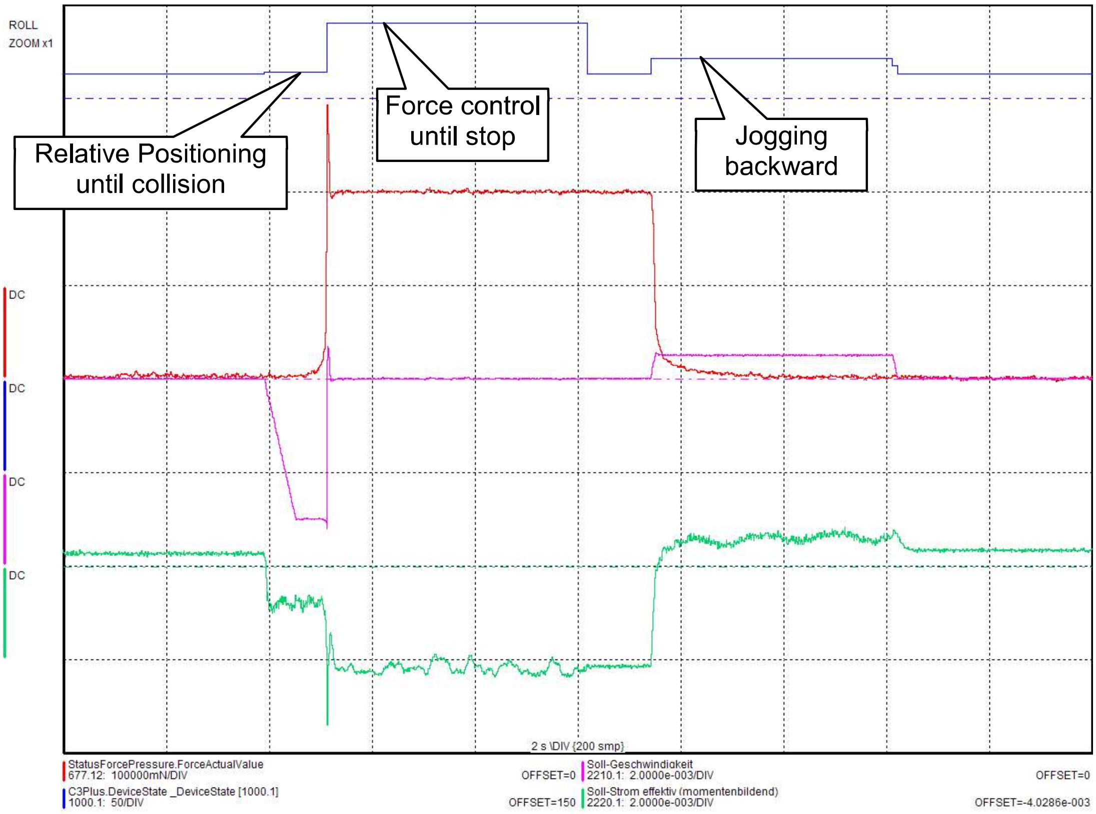
This function bloc performs immediate copy of force reference to reference generator parallel to IEC function block.

Program name			Task_500()	
Actual force signal scaling (optional)				
VAR_IN_OUT				
VAR_INPUT				
	Mode		BOOL	Mode from C3_PressureForceAbsolute
	Setpoint		REAL	Force demand value in mN (if Unit_factor = 0.001)
VAR_OUTPUT				

Attention: Application example provides a test function for desktop tests which must be inactive in real applications: direct copy of actual current into AnalogIn0Forced can be used when there is no force sensor connected.

8.6 Timing Diagram





8.7 Initialization Init_Defaults()

Everything that can be once initialized with the start of IEC and needs not be changed during function, should be stored here.

8.8 IEC program variations

In some applications product may move slowly when force is applied until a specific position, where it may break away. In this case a position comparator in IEC program may be useful to execute internal stop.

9 Interfaces of the application example

9.1 Parameter interface

The control parameters are transferred in the variable array (9 columns with 32 rows each). If necessary, they can be burnt into flash after the update (takes about 2s) so that they can serve as default values after switching on the voltage again.
The contents depend on the formats of the array variables.

	Col1	Col2	Col3	Col4	Col5	Col6	Col7	Col8	Col9
Row	REAL	REAL	INT	INT	INT	DINT	DINT	DINT	DINT
1	*Force_Out*		*StatusBits*						
2	*Force_Act*		*State_force*						
3	*Force_Err*								
4									
5	Unit-Factor								
6	nomForce	JogSpeed	Curr_Lim			JogAL	JogDL	JogJerkAL	JogJerkDL
7	PosRel	PosSpeed	Control			PosAL	PosDL	PosJerkAL	PosJerkDL
8	Force_Ref	HomeSpeed	Threshold						
9	Force_Gain	SpeedLim	Gradient						
10	Force_Offset		SensorType						
11	Force_Scale		Channel						
12			Force Mode						
13			Val1						
14			Val2						
15			Out						
16			Time						
…									
32									

Test function: Reference oszillator

Only for debugging

Do not modify these objects in IEC program, they are reserved for application wizard

9.2 Binary control signals

Control bit input:

Bit	Name	Description
0	Enable	Power enable (position control mode) ↓: Error quit
1	Start	↑: Start relative move and execute force control when actual force exceeds threshold 1: Enable force control ↓: Disable force control, Stop
2	JogP	↑: Jog forwards ↓: Stop
3	JogN	↑: Jog backward ↓: Stop
4	Home	↑: Homing
5	End1Ini	Limit switch 1
6	End2Ini	Limit switch 2
7	RefIni	reserved for Reference switch

9.3 Binary status signals

Status bits:

Bit	Name	Description
0	Powered	Drive energized
1	Referenced	Axis referenced
2	Fault	Malfunction
3		
4		
5		
6		
7		

10 Optimization&setup

Steps to perform during first setup:

1. Calculate load inertia or use load identification
2. Increase current bandwidth to maximum
3. Check if direction sense is ok, change direction if necessary, decide homing mode
4. Increase stiffness to maximum by use of test movement
5. Connect force sensor and scale analog input in a no load position (gain = -1, offset = -displayed value) optimization target: Iin = 0…20mA -> O19x.5 = 0 … 1.0
6. Check signal direction by use of a small P-part in force controller; negative feedback must be given; if necessary change sign of gain factor in application wizard

10.1 Standard Structure (F-I)

In general it is difficult to define universally applicable formula to find the right parameters, because the parameters are dependent on the controlled system (mechanical stiffness e.g).
Once we have done a couple applications it may imaginable, that based on our and customers experience it will be possible to make some definitions.

Definition of major characteristics of the closed-loop step response:

- Rise time (the time it takes for the plant output y to rise beyond 90% of the desired level for the first time)
- Overshoot: how much the peak level is higher then the steady state, normalized against the steady state.
- Settling Time: the time it takes for the system to converge to its steady state.
- Steady-state Error: the difference between the steady-state output and the desired output.

Today we have to proceed in a typical way:

10.1.1 Current loop bandwidth

To increase bandwidth of current control loop it is often possible to set O2100.8 up to 100%.

Current loop - Bandwidth [2100.8]	50	%
Current loop - Damping [2100.9]	100	%

10.1.2 Step 1: Tuning of P-Part

First use **Kp** O2215.5 to decrease **Rise time** and **Steady-state error** (Overshoot could increase)

10.1.3 Step 2: Tuning of Speed feedback

By adding speed feedback it may be possible to improve stability of force control loop.
Use **Kv** O2215.9 to increase damping of the system (Rise time could increase). Note: Set velocity feedback limitation Limit Kv O2215.13 fix to 100% ==> no limitation usually necessary (only for hydraulic pump pressure control important)

10.1.4 Step 3: Add I-Part if necessary

Use **Ki** O2215.6 to eliminate **Steady state error** and decrease **Rise time** (Overshoot and Settling time could increase) Note: Set inner window O2215.7 fix to 0 and outer window O2215.8 fix to maximum force!

10.1.5 Step 4: Use of dead band

Also try to improve stability by use of dead band if backlash may be present. In this case inner window O2215.7 can be increased to small force values which are greater than backlash.

10.1.6 Step 5: Use of force feed forward

Use Kffw O2215.10 in hydraulic systems as disturbance Add on signal to reduce negative influence of the integral Part Ki

10.2 Advanced Structure (F-N-I) & fixed load (e.g. press application)

When speed and position control is tuned the best, force controller is activated with all coefficients set to zero.

10.2.1 Step 1: Tuning of P-Part

First use **Kp** O2215.5 to decrease **Rise time** and **Steady-state error** (Overshoot could increase)

10.2.2 Step 2: Tuning of I-Part

Use **Ki** O2215.6 to eliminate **Steady-state error** (Overshoot and Settling time could increase) Note: Set inner window O2215.7 fix to 0 and outer window O2215.8 fix to maximum force!

10.3 Advanced Structure (F-N-I) & moving load (e.g. pedal force simulation)

With moving load like a pedal in a flight simulator start with I-Part (which acts as inertia) and use P-Part as damping factor.

10.3.1 Step 1: Tuning of I-Part

First use **Ki** O2215.6 to decrease **Rise time** and eliminate **Steady-state error** (Overshoot and instabilities could increase if pedal touches mechanical boundary)
Note: Set inner window O2215.7 fix to 0 and outer window O2215.8 fix to maximum force!

10.3.2 Step 2: Tuning of P-Part

Use **Kp** O2215.5 to eliminate **instabilities.**

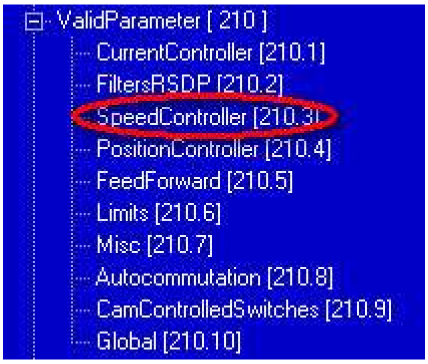
10.3.3 Step 3: Increase filter coefficient

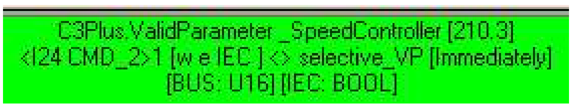
Analog input can be filtered by O170.2 to reduce noise

10.4 Switching between controller settings in IEC program

In some applications switching between different controller settings may be necessary to adapt tuning to different load situations.
Therefore controller parameters have to be written by IEC …

and a selective VP has to be performed:



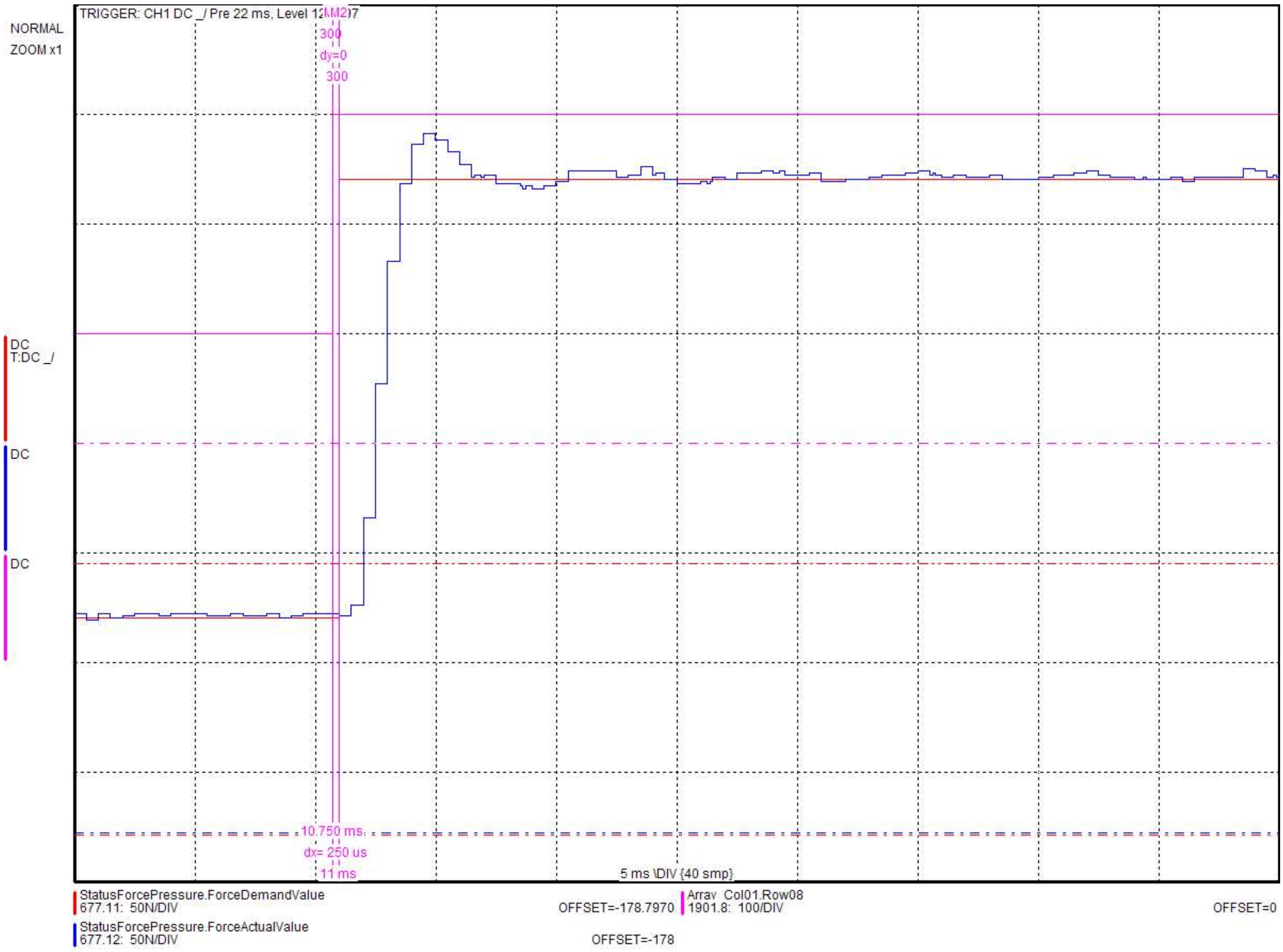


C3Plus.ValidParameter-SpeedController := TRUE;

11 Test performance & applications

11.1 Desktop Test

In this situation actual motor current is directly copied into analog input 0 forced due to lack of force sensor and appropriate mechanic.
Force controller is used in mode 3 = Force-Current cascade.

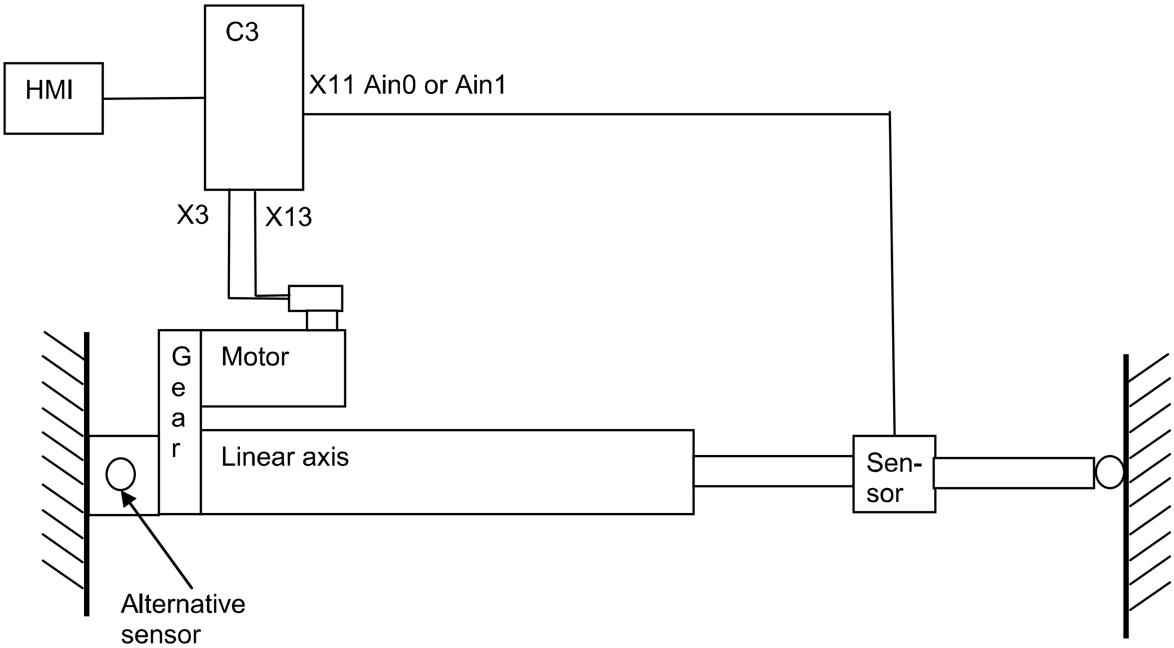


Red: Force demand value
Blue: Force actual value
Pink: Fieldbus reference value

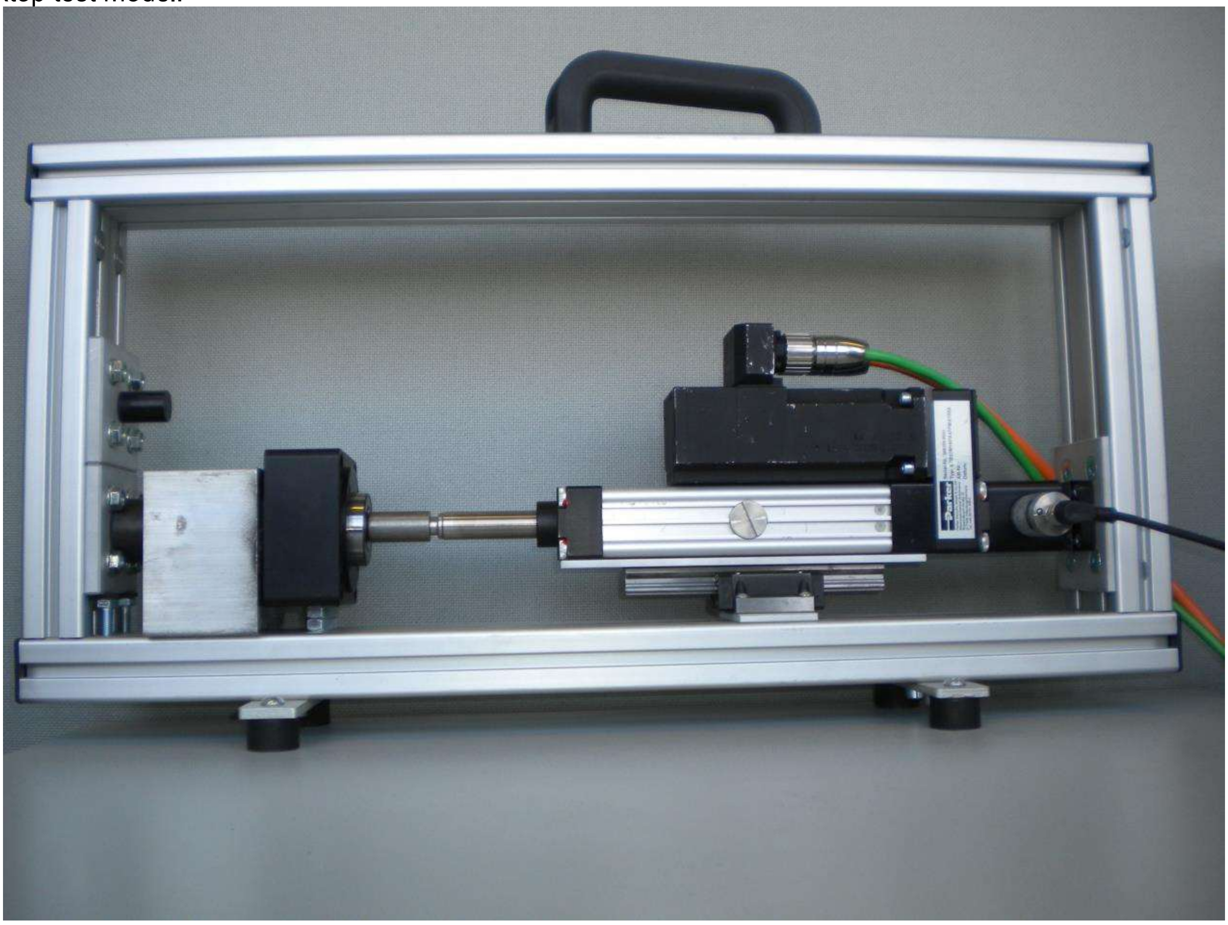
Controller tuning:
KP O2215.6 = 0.05
KI O2215.7 = 120

11.2 Spindle application

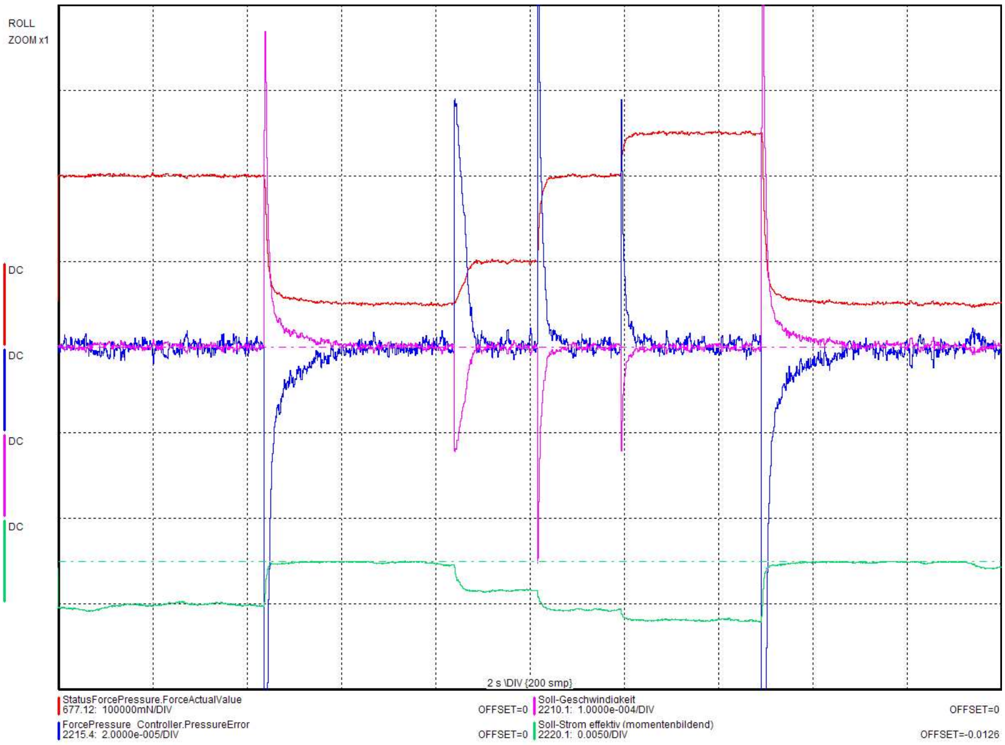
Force controller is used in mode 4 = Force-Speed-Current cascade.
Analog input filter O170.3 = 550% (maximum)



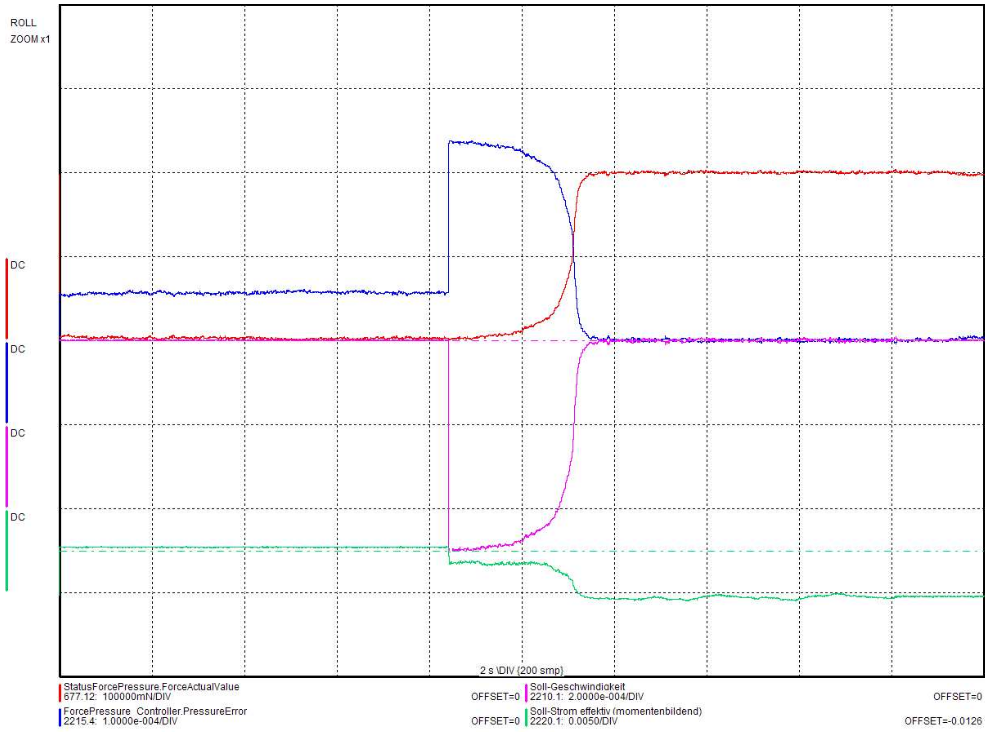
Desktop test model:



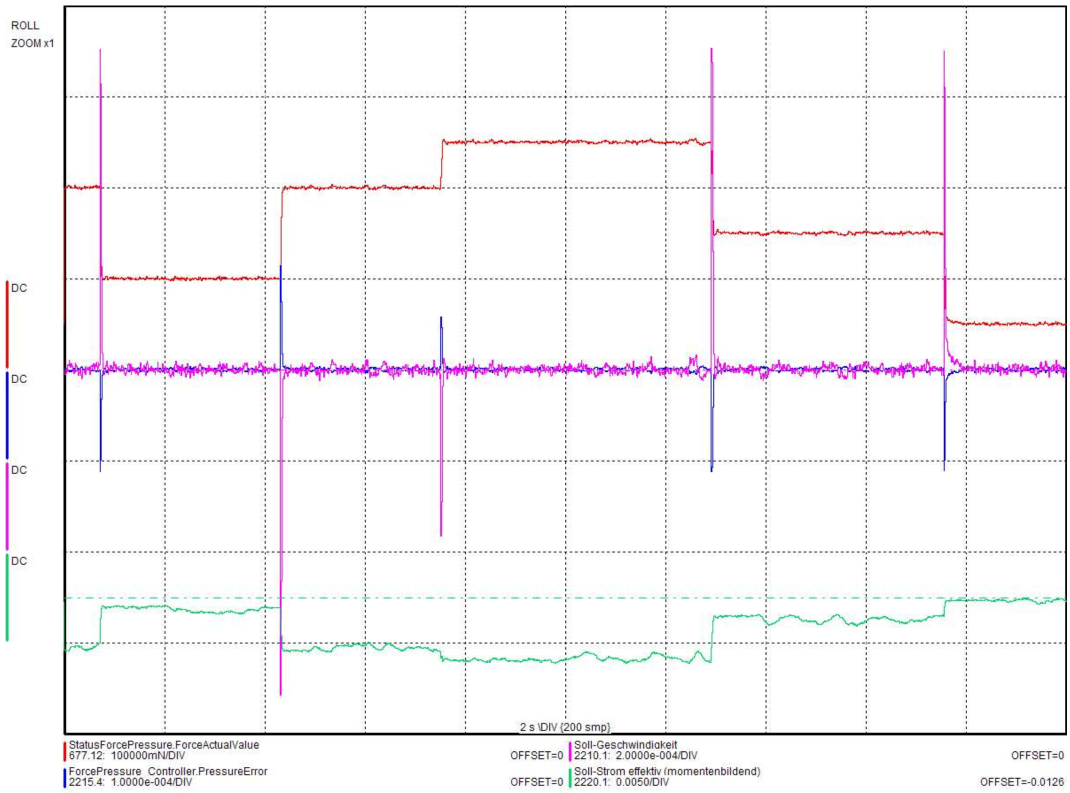
Sensor flange:



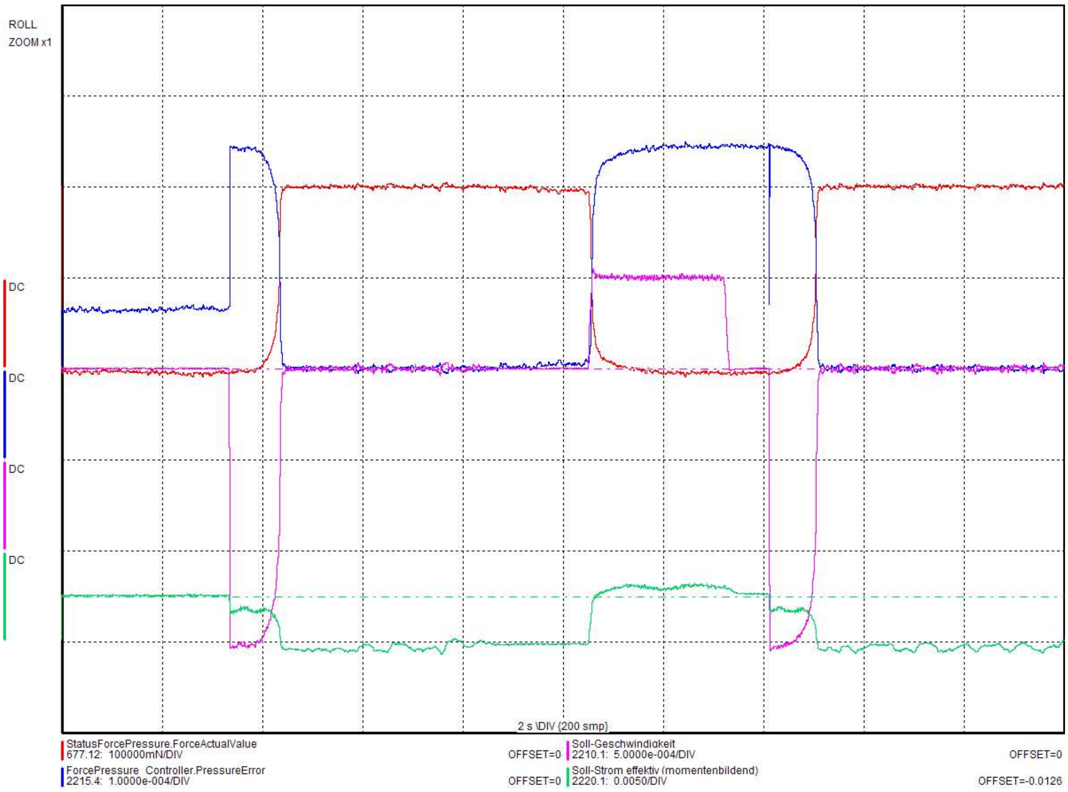
Step response in force control, standing in contact to semi elastic load (thick paper stack):
Fref = 200 -> 50 -> 100 -> 200 -> 250 -> 50
KP = 0.01
KI = 0



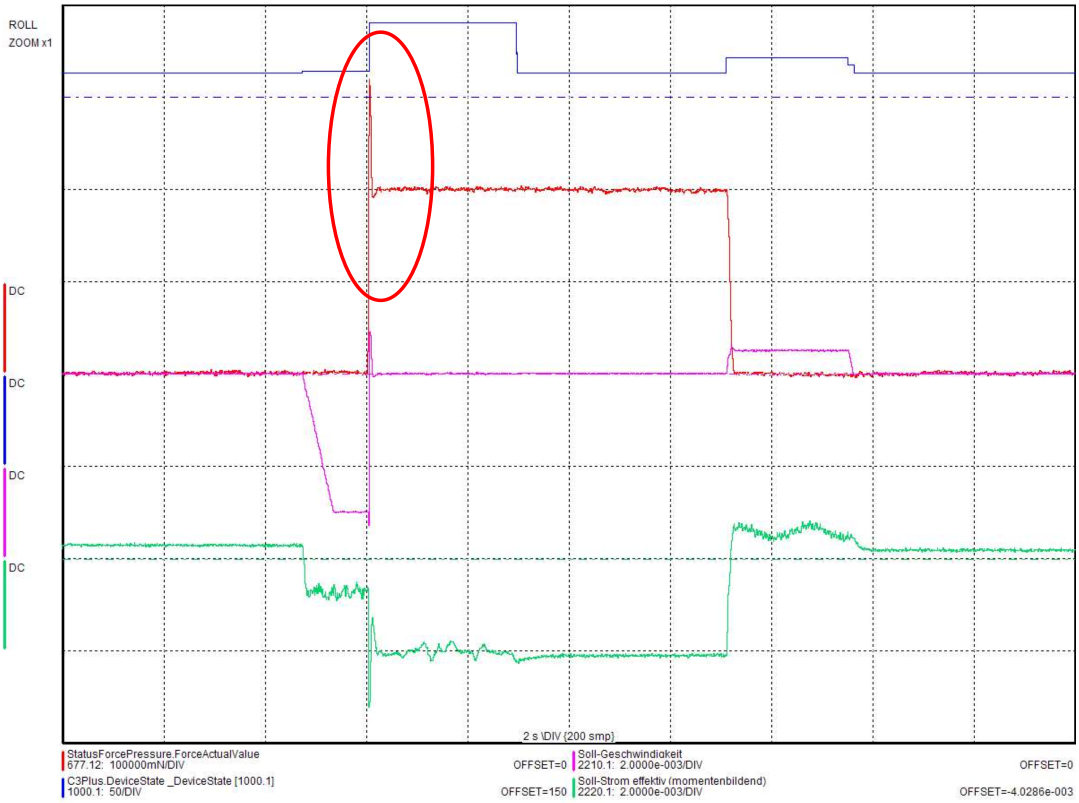
Activation force control from standstill without contact to load -> moving against load with constant speed resulting from force error * KP with Fref = 200N



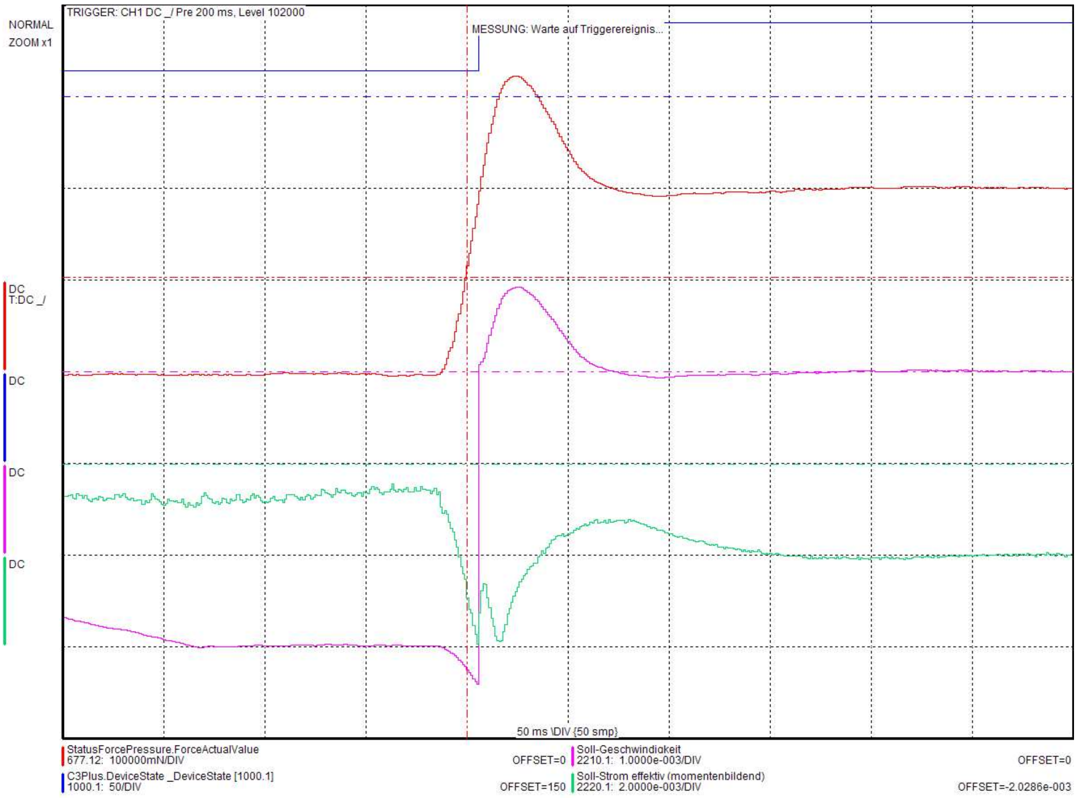
Step response with KP = 0.03, KI = 0

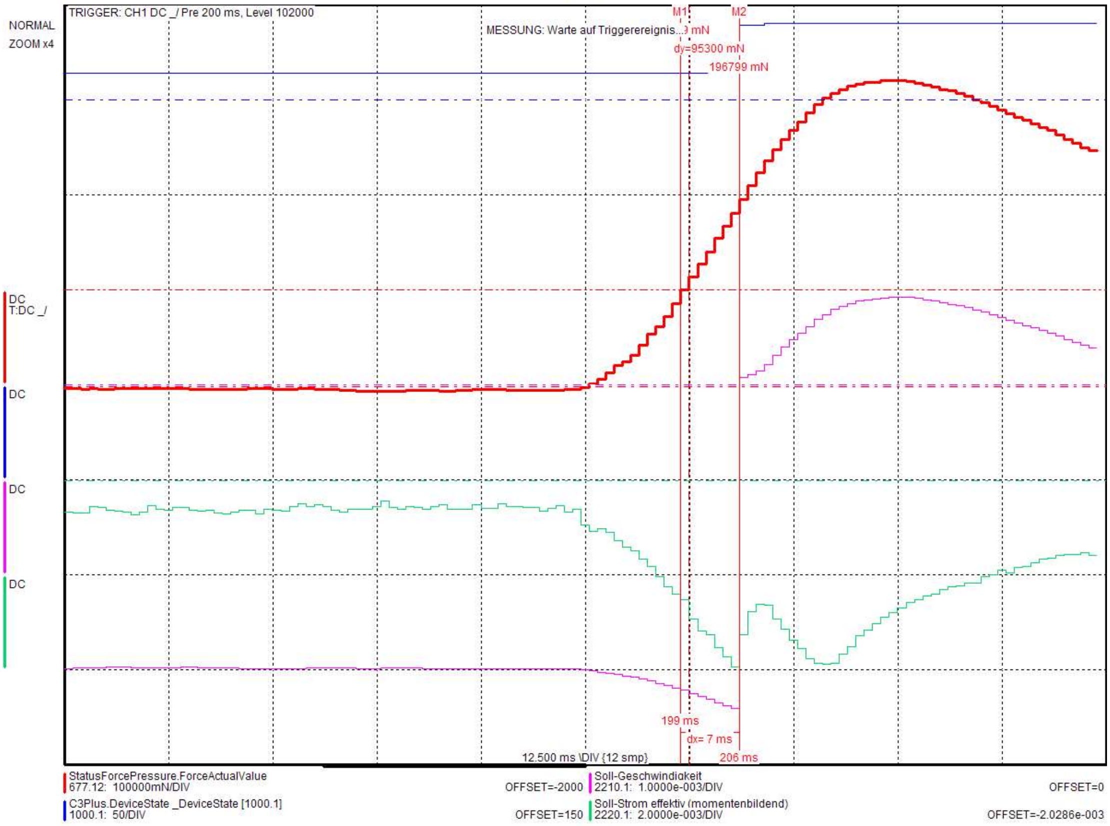


Drive against load with force control activated -> return travel with jogging (endless positioning mode) -> touch load again with active force control

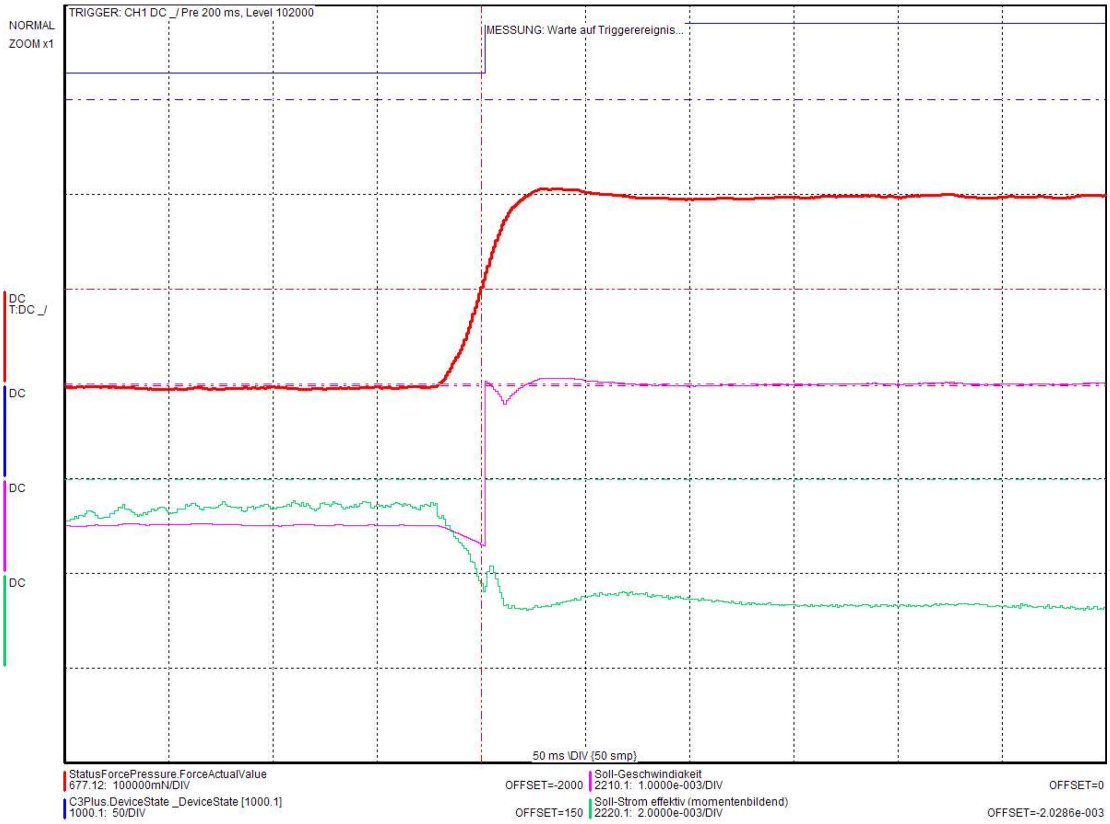


Travel with relative positioning and speed = 60mm/s against mechanical blok with rubber damping.

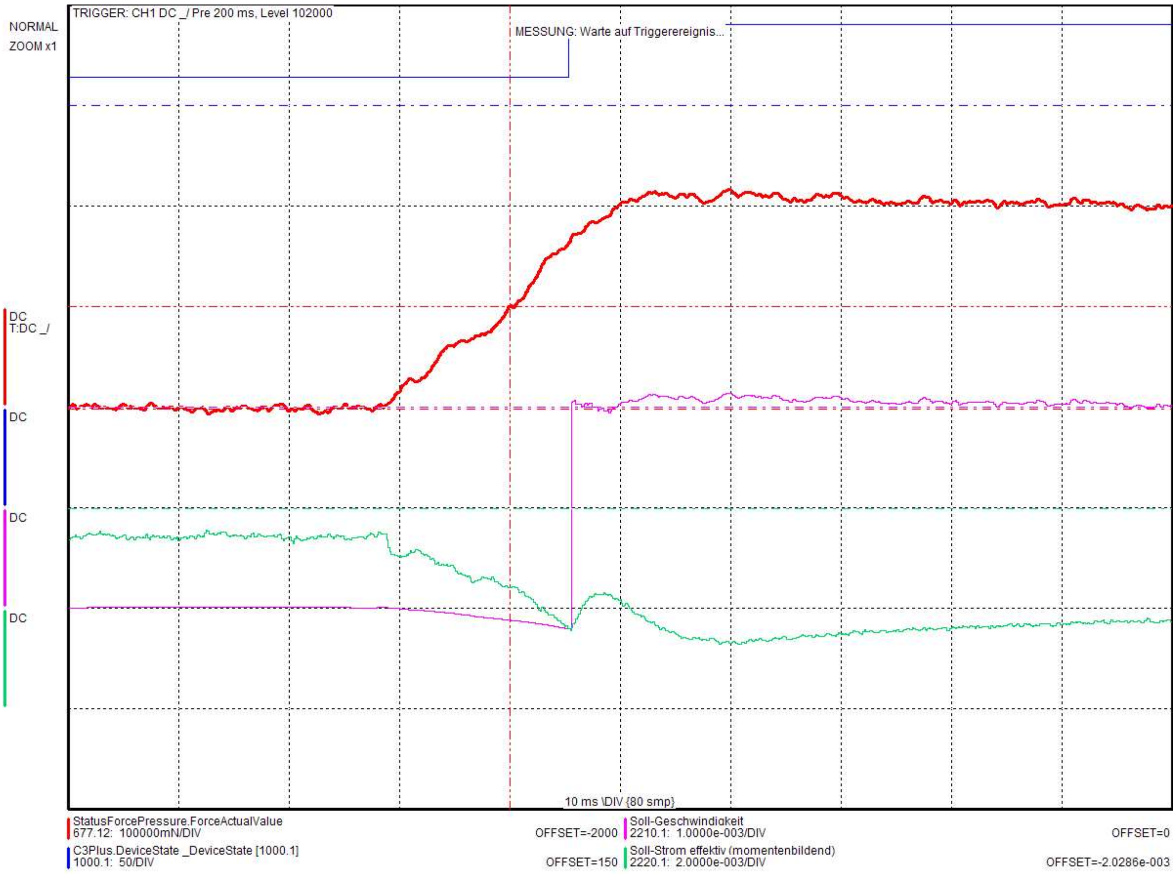




At the moment of contact current increases, reference speed increases due to tracking error and force increases above threshold 100N (marker 1). IEC cycle time = 10ms. Here, after 7ms device mode is changed into 39 (change force) and 40 (keep force constant), force is controlled at 200N.



Overshoot in actual force can be strongly reduced by touching mechanical block with less speed (30mm/s).



Analog input filter reduced from 550% to 500% and speed at 40mm/s

Note: please keep input filter as high as possible due to signal noise reduction.