Training Document for Comprehensive Automation Solutions

Totally Integrated Automation (T I A)

MODULE B3

Control Engineering with STEP 7

This document has been written by Siemens AG for training purposes for the project entitled "Siemens Automation Cooperates with Education (SCE)".
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We would like to thank the following: Michael Dziallas Engineering, the teachers at vocational schools, and all others who helped to prepare this document.

Table of Contents

PAGE

1. Preface **5**

2. Fundamentals of Control Engineering **7**

2.2 Components of a Control Loop 8
2.3. Characteristics 11
2.4 Step Function for Examining Controlled Systems 12
2.5. Self-Regulating Processes 13
2.5.1. Proportional Controlled System without Time Delay 13
2.5.2. Proportional Controlled System with a Time Delay 14
2.5.3 Proportional Controlled System with Two Time Delays 15
2.6 Controlled Systems without Inherent Regulation 17
2.7 Types of Controllers 18
2.7.1 Two Position Controllers 18
2.7.2 Three Position Controllers 20
2.7.3 Basic Types of Continuous Controllers 21
2.8 Objectives for Controller Adjustment 27
2.9 Digital Controllers 29

3. Discontinuous Action Controller as Two Position Controller **31**

3.1 Function and Problem Description 31
3.2 Possible Solution for the PLC Program: 34

4. Controller Block (S)FB41 "CONT_C" as Software PID Controller in STEP 7 **37**

4.1 Task Definition for PID Standard Controller 37
4.2 (S) FB 41 “CONT_C“ 39
4.3 Exercise Example 40

5. Setting Controlled Systems **54**

5.1 General 54
5.2 Setting the PI-Controller according to Ziegler-Nichols 55
5.3 Setting the PID Controller according to Chien, Hrones and Reswick 55
5.4 Exercise Example 57

6. Appendix **60**

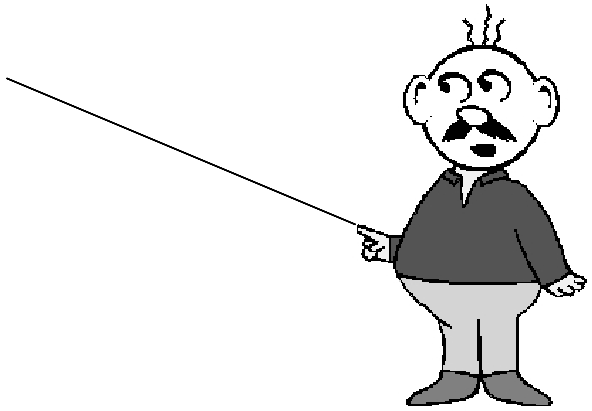
The following symbols provide a guide through this B3 module:

ℹ **Information**

🖥 **Programming**

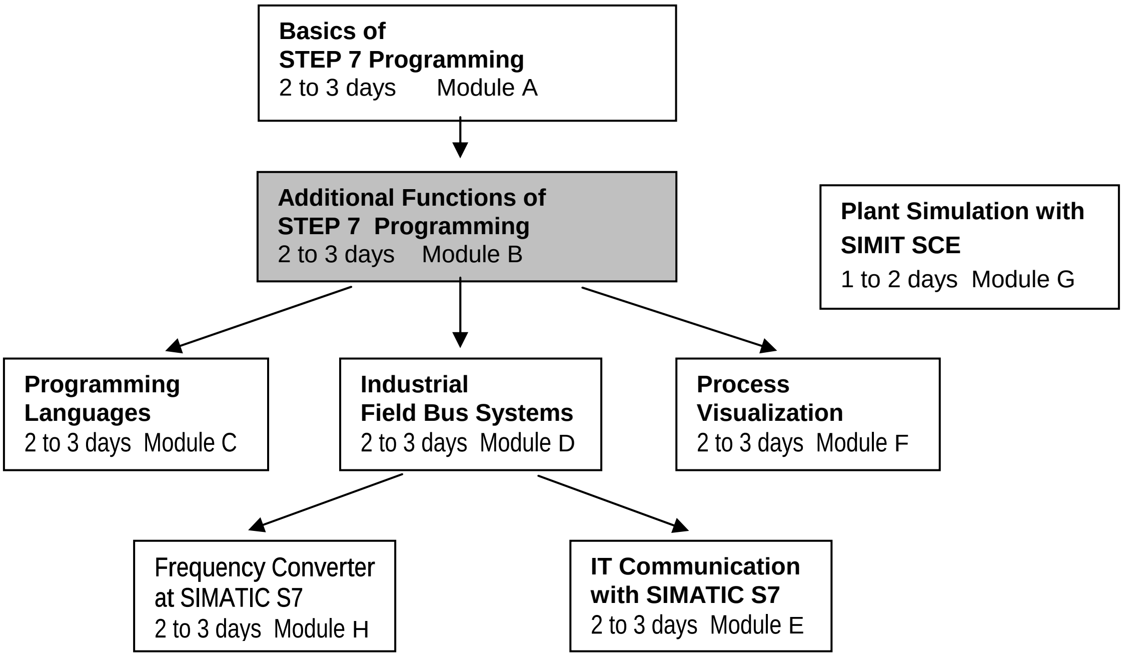
? **Exercise Example**

⚠ **Notes**



1. PREFACE

In terms of its contents, Module B3 is part of the teaching unit entitled **"Additional Functions of STEP 7 Programming'**.



Basics of STEP 7 Programming
2 to 3 days Module A

Additional Functions of STEP 7 Programming
2 to 3 days Module B

Plant Simulation with SIMIT SCE
1 to 2 days Module G

Programming Languages
2 to 3 days Module C

Industrial Field Bus Systems
2 to 3 days Module D

Process Visualization
2 to 3 days Module F

Frequency Converter at SIMATIC S7
2 to 3 days Module H

IT Communication with SIMATIC S7
2 to 3 days Module E

Learning Objective:

In module B3, the reader learns the following: how a PID controller is integrated into a STEP7 program, how it is wired to analog process variables, and how it is started. The following steps are discussed:

- Program example for a two position controller
- Calling a PID controller in a STEP 7 program
- Wiring the PID controller to analog process variables
- Setting the controller parameters at the PID controller

Prerequisites:

To successfully work through Module B3, the following knowledge is assumed:

- Knowledge in handling Windows
- Fundamentals of PLC programming with STEP 7 (for example, Module A3 – 'Startup' PLC Programming with STEP 7)
- Analog Value Processing with STEP 7 (for example, Module B2 – Analog Value Processing)

Hardware and software required

1 PC, operating system Windows 2000 Professional starting with SP4/XP Professional starting with SP1/Server 2003 with 600MHz and 512RAM, free hard disk storage 650 to 900 MB, MS Internet Explorer 6.0

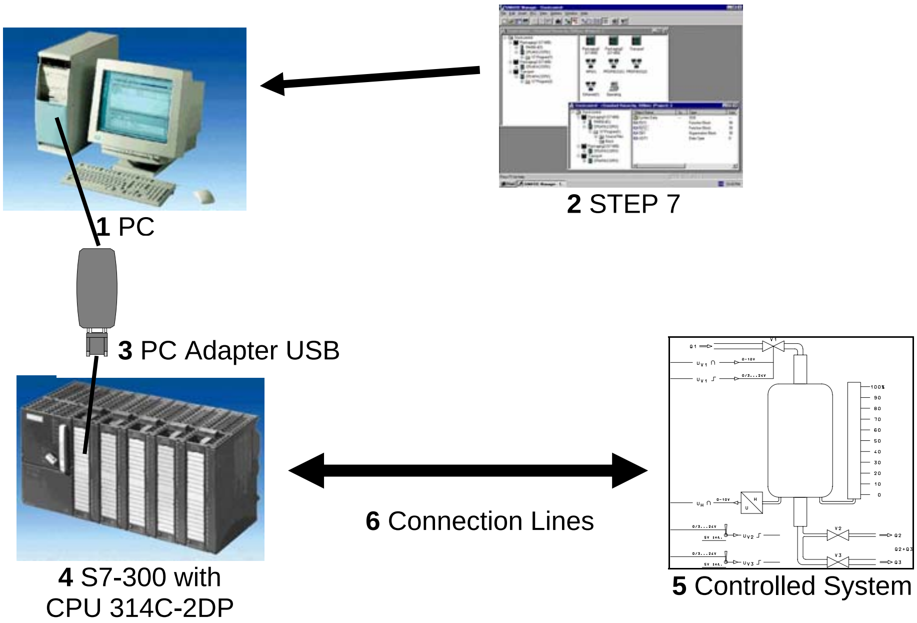
2 Software STEP7 V 5.4

3 MPI interface for the PC (for example, PC adapter USB)

4 PLC SIMATIC S7-300 with at least one analog input/output module to which, at one analog value input, a potentiometer or another analog signal transmitter is connected. In addition, an analog value display has to be connected to at least one analog output.
Sample configuration:
- Power supply: PS 307 2A
- CPU: CPU 314C-2DP

5 Controlled System

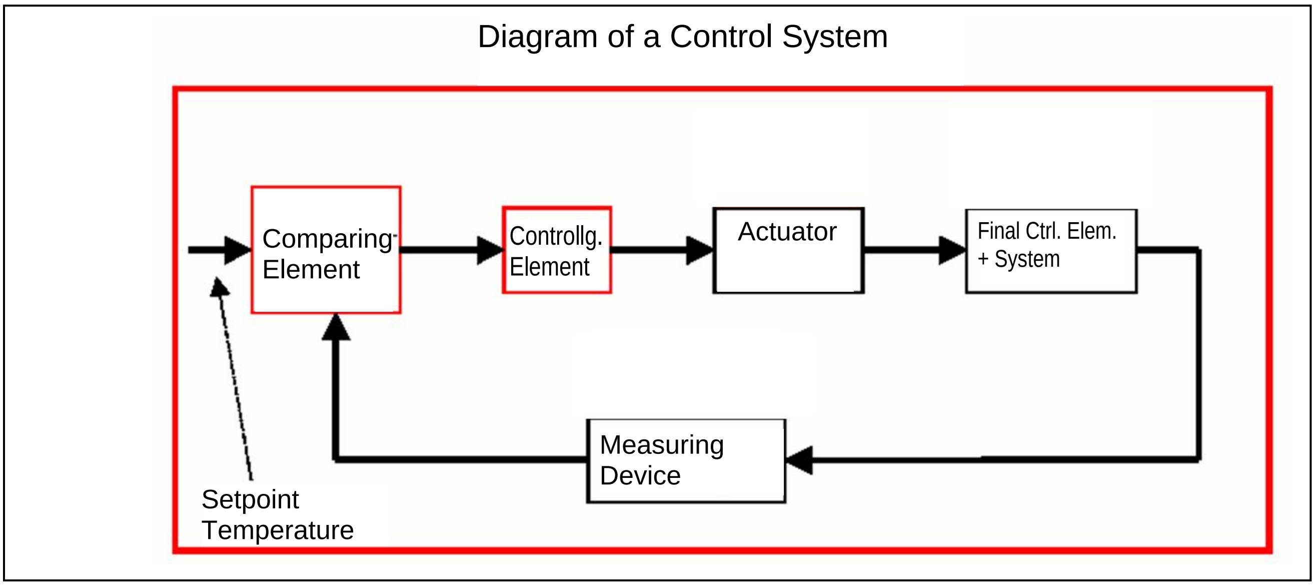
6 Connection lines for connecting the controlled system to analog inputs and outputs of the PLC



2. FUNDAMENTALS OF CONTROL ENGINEERING

2.1 Tasks of Control Engineering

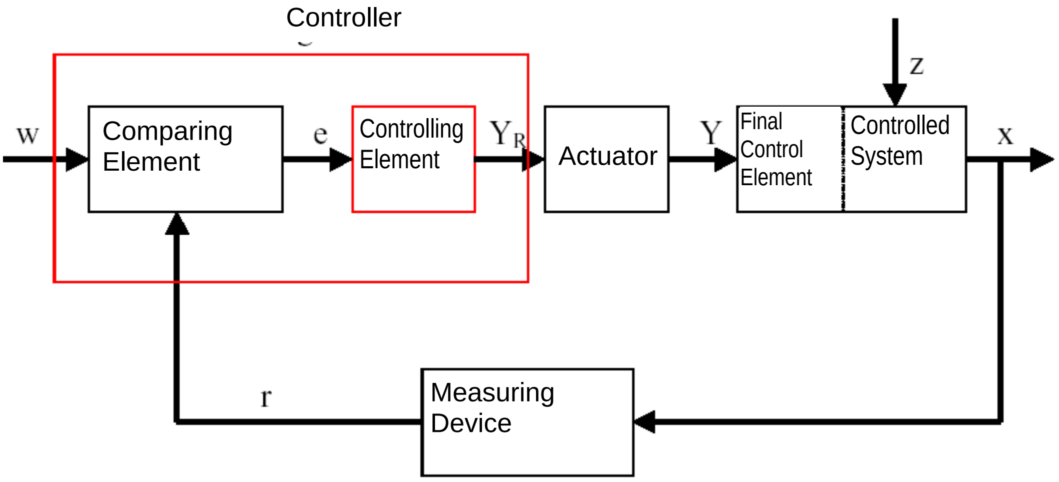
"Closed loop control is a process where the value of a variable is established and maintained continuously through intervention based on measurements of this variable. This creates a sequence that takes place in a controlled loop -the closed loop- because the process is executed based on measurements of a variable that is in turn influenced by itself.“
The variable to be controlled is measured continuously and compared with another specified variable of the same kind. Depending on the result of this comparison, the control process adjusts the variable to be controlled to the specified variable.



2.2 Components of a Control Loop

Below, the basic terminology of control engineering is explained in detail.

First, an overview shown in the diagram below:



1. The Controlled Variable x

It is the actual “objective“ of the control process: the variable that is to be influenced or kept constant is the purpose of the entire system. In our example, that would be the room temperature. The momentary value of the controlled variable existing at a certain time is called "actual value“ at that point in time.

2. The Feedback Variable r

In a control loop, the controlled variable is constantly checked in order to be able to respond to unintended changes. The measured variable proportional to the controlled variable is called feedback variable. In the example "furnace“, it would correspond to the measured circuit voltage of the inside thermometer.

4. The Disturbance Variable z

The disturbance variable is the variable that unintentionally influences the controlled variable, and moves it from the current setpoint value. A fixed setpoint control is necessary, for example, because a disturbance variable exists. For the heating system considered here, this would be the outside temperature, for example, or any other variable that changes the room temperature from its ideal value.

5. The Setpoint Value w

The setpoint value at a point in time is the value that the controlling variable should ideally have at that time. It should be noted that the setpoint value can change continuously under certain circumstances if there is a slave value control. The measured value that the measuring device used would establish if the controlled variable would have exactly the setpoint value is the instantaneous value of the reference variable. In the example, the setpoint value would be the room temperature desired at that time.

6. The Comparing Element

This is the point where the current measured value of the controlled variable and the instantaneous value of the reference variable are compared. In most cases, both variables are measured circuit voltages. The difference of both variables is the “control deviation“ e. It is passed on to the controlling element, and evaluated there (see below).

7. The Controlling Element

The controlling element is the actual center piece of a control system. It evaluates the system deviation -that is, the information about whether, how and to what extent the controlled variable deviates from the current setpoint- as input information, and derives from this the **“Controller output variable“ Y_R** which, ultimately, influences the controlled variable. The controller output variable would be, in the example of the heating system, the voltage for the mixer motor.
The manner in which the controlling element determines the controller output variable from the system deviation is the main criterion of the control system. Part II discusses this topic in greater detail.

8. The Actuator

The actuator is the “executing organ“, so to speak, of the control system. In the form of the controller output variable, the controlling element provides the actuator with information as to how the controlled variable is to be influenced, and implements it into a change of the “manipulated variable“. In our example, the actuator would be the mixer motor. Depending on the voltage supplied by the controlling element (that is, the controller output variable), it influences the position of the mixer (which here represents the manipulated variable).

9. The Controlling Element

This is the element of the control loop that influences the controlled variable (more or less directly), depending on the **manipulated variable Y**. In the example, this would be the combination consisting of the mixer, the furnace lines, and the heater. The mixer motor (actuator) sets the mixer (the manipulated variable). By means of the water temperature, the room temperature is influenced.

10. The Controlled System

The controlled system is the plant where the variable to be controlled is located; in the example of the radiator, the living space.

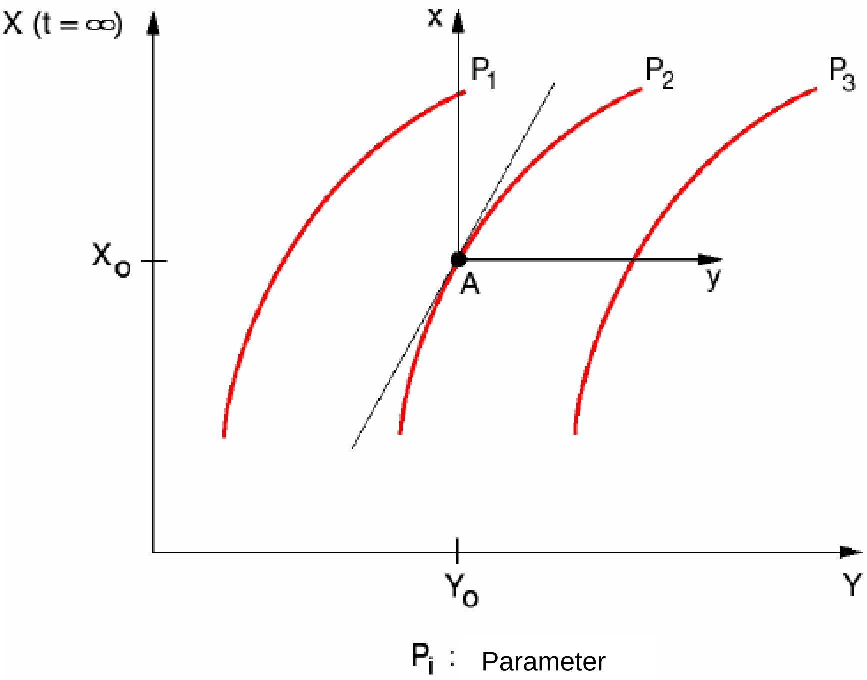
11. Dead Time

Dead time refers to the time that passes, starting with a change of the controller output variable until a measurable reaction by the controlled system. In our example, it would be the time between a change of the voltage for the mixer motor, and the measurable change in room temperature caused by this.

2.3. Characteristics

Controlled systems in which a new constant output value sets itself after a certain time has passed are called 'self-regulating process'.

The relationship of the output variables to the input variables in the steady state results in a characteristic.



P_i : Parameter

In the environment of an operating point, the characteristic is replaced with a tangent. In the environment of an operating point, the problem is treated as a linear problem.

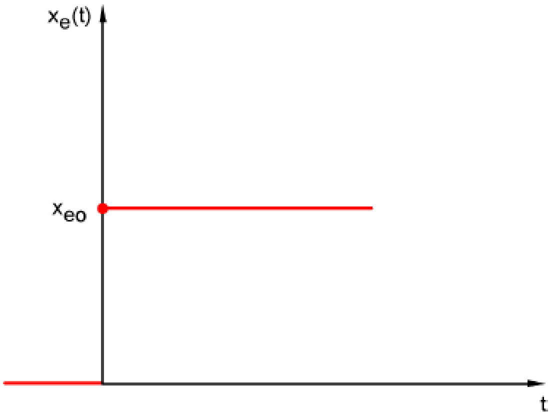
The zero point of the variables x(t), y(t) and z(t) refers to the operating point A:

:

x = X – Xo y = Y - Yo z = Z - Zo

2.4 Step Function for Examining Controlled Systems

To examine the behavior of controlled systems, controllers and control loops, a uniform function is used for the input signal: the step function. Depending on whether a control loop element or the entire control loop is examined, the step function can be assigned to the following: the controlled variable x(t), the manipulated variable y(t), the reference variable w(t) or the disturbance variable z(t). For that reason, the input signal, the step function, is often designated as xe(t), and the output signal as xa(t).

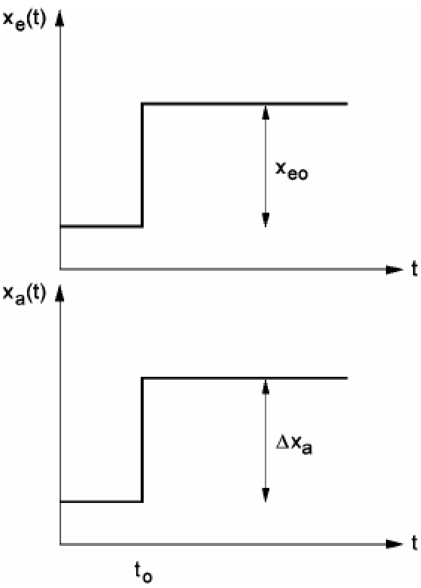


$$x_e(t) = \begin{cases} 0 & \text{for} \quad t < 0 \\ x_{eo} & \text{for} \quad t \geq 0 \end{cases}$$

2.5. Self-Regulating Processes

2.5.1. Proportional Controlled System without Time Delay

The controlled system is called P-system for short.



Abrupt change of the input variable for i t_0

Controlled Variable/
Manipulated Variable

$x = K_{ss} \bullet y$

K_{SS}: Proportional coefficient for a manipulated variable change

$$K_{ss} = \frac{\Delta x}{\Delta y} = \tan\alpha$$

Controlled Variable/
Disturbance Variable

$x = K_{sz} \bullet z$

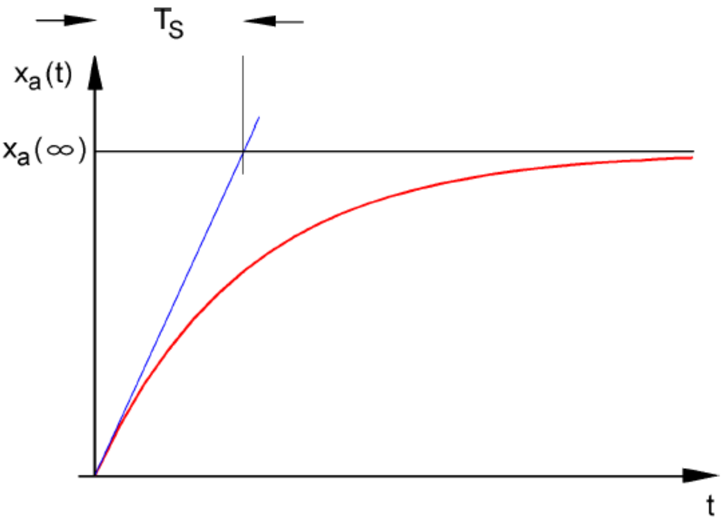
K_{SZ}: Proportional value for a disturbance variable change

Range: $y_h = y_{max} - y_{min}$

Control Range: $x_h = x_{max} - x_{min}$

2.5.2. Proportional Controlled System with a Time Delay

The controlled system is called P-T1 system for short.



Differential equation for a general input signal $x_e(t)$:

$$T_S \bullet \dot{x}_a(t) + x_a(t) = K_{PS} \bullet x_e(t)$$

Solution of the differential equation for a step function at the input (step response)

$$x_a(t) = K_{PS}\ (1 - e^{-t/T_S}) \bullet x_{eo}$$

$$x_a\ (t = \infty) = K_{PS} \bullet x_{eo}$$

T_S: Time constant

2.5.3 Proportional Controlled System with Two Time Delays

The controlled system is called P-T2 system for short.

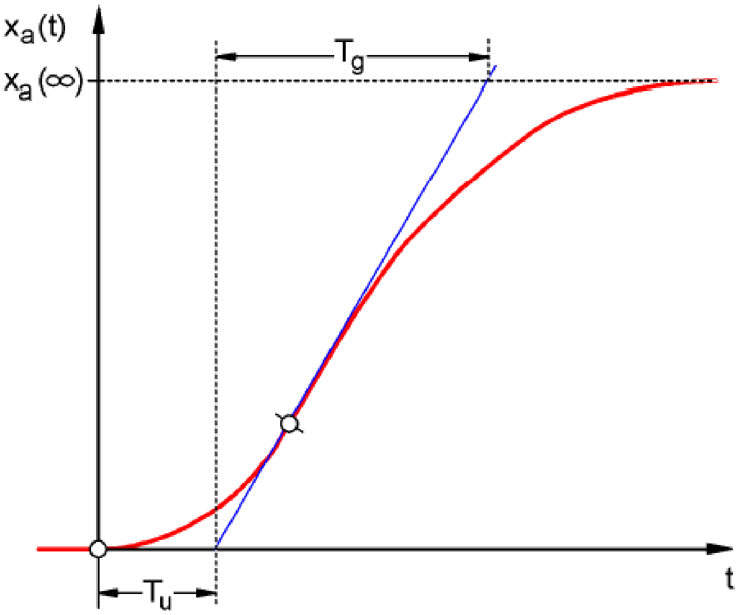


Figure: Jump Response of the P-T2 system

Tu: Delay time Tg: Transition time

The system consists of the reaction-free series connection of two P-T1 systems that have the time constants TS1 and TS2.

Controllability of P-Tn systems:

$\frac{T_u}{T_g} < \frac{1}{10} \rightarrow$ Easy to control

$\frac{T_u}{T_g} \approx \frac{1}{6} \rightarrow$ Can still be controlled

$\frac{T_u}{T_g} > \frac{1}{3} \rightarrow$ Difficult to control

With the rising ratio Tu/Tg, controlling the system becomes more and more difficult.

2.5.4 Proportional Controlled System with n Time Delays

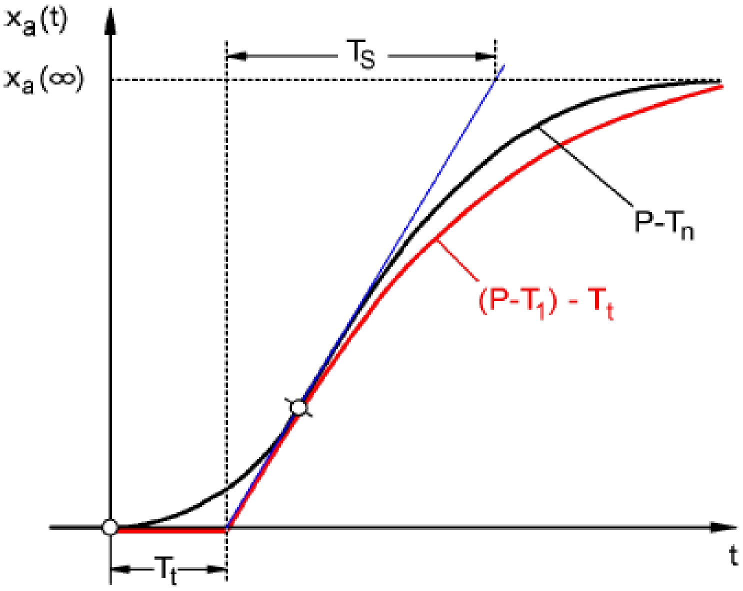
The controlled system is called P-Tn system for short.

The time response is described with a differential equation of the nth degree.

The characteristic of the step response is similar to that of the P-T2 system. The time response is described through Tu and Tg.

Substitute: The controlled system with many delays can be approximately substituted with the series connection of a P-T1 system with a dead time system.

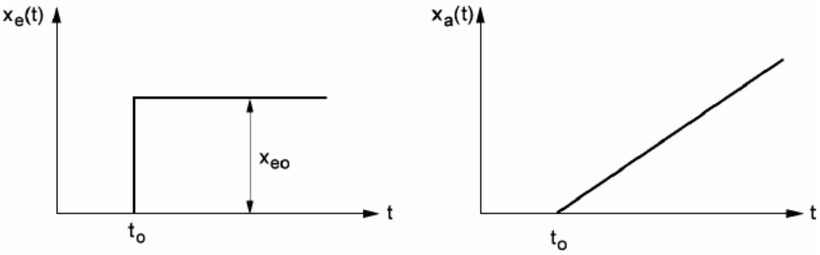
The following applies: Tt » Tu and TS » Tg.



Substitute step response for the P-Tn system

2.6 Controlled Systems without Inherent Regulation

The controlled variable continues to grow after a fault, without aiming for the high range value.

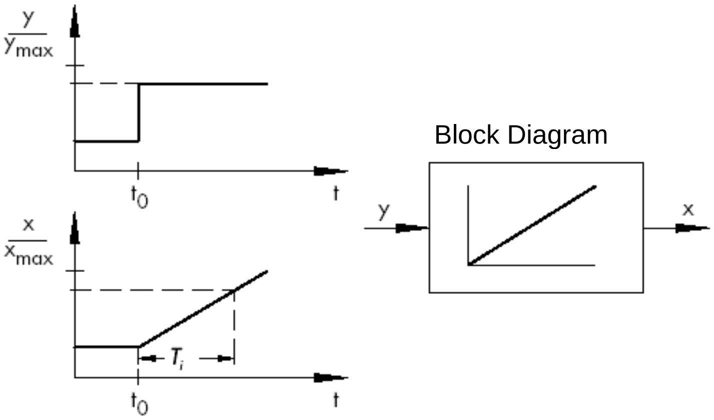


Example: Level Control

In the case of a container with a drain whose inflow volume stream and outflow volume stream are the same, a constant level is the result. If the flow rate of the inflow or the outflow changes, the liquid level rises or falls. The larger the difference between inflow and outflow, the faster does the level change.

The example shows that in practice, the integral action usually has limits. The controlled variable rises or fills up only so long until it has reached a limit that is contingent on the system: the container overflows or empties, the pressure reaches the plant maximum or minimum, etc..

The figure shows the trend of an I-system when there is an abrupt change of the input variable, as well as the block diagram derived from it.



If the step function at the input changes into any function xe(t), the following happens:

$x_a(t)=K_{IS} \int x_e(t)\,dt$ ⇒ integrating controlled system

K_{IS}: integral coefficient of the controlled system

2.7 Types of Controllers

2.7.1 Two Position Controllers

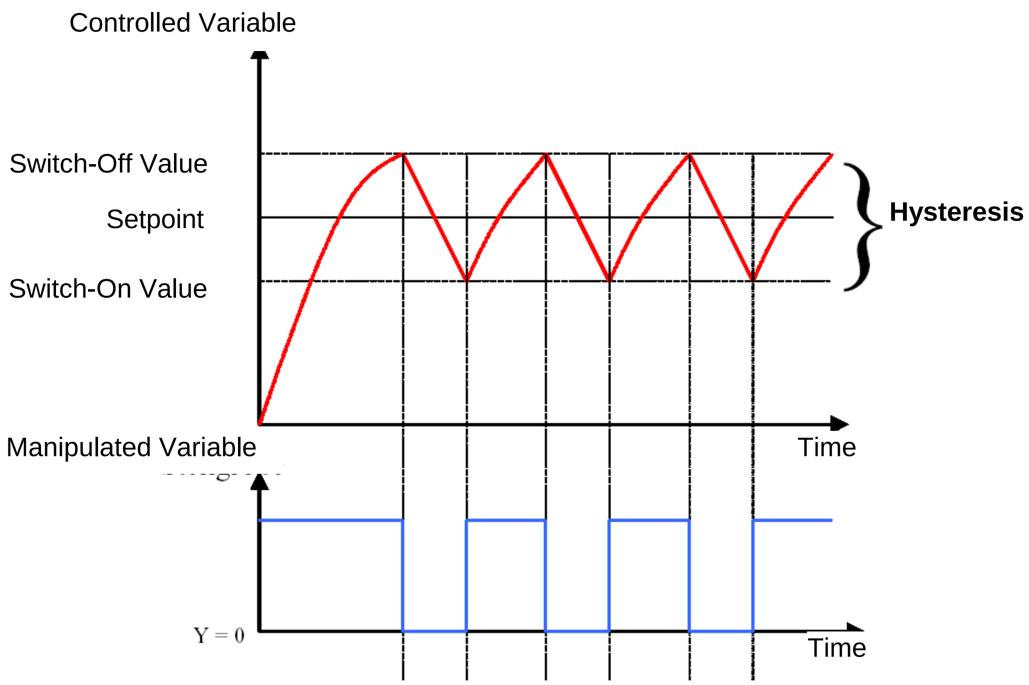
The essential feature of two position controllers consists of their knowing only two modes: “On“ and “Off“ -which makes them the simplest type of controller. Two-position controllers are used primarily when adhering to a setpoint exactly is less important than to keep the control system as simple as possible; or, when the actuator or the final control element does not allow for a continuous control system. The heating system mentioned several times above is -with a control loop having a room thermometer and a mixer- a continuous control system. To keep the water temperature in the boiler loop constant, typically a two position controller is used since it can, on the one hand, fluctuate by a few degrees, and on the other hand it is clearly simpler to switch the burner on and off than to do an exact dosing of fuel to be added.

Since theoretically -to adhere to the setpoint exactly- it would be necessary to switch a system on and off infinitely fast, the two position controller has a so-called “hysteresis“. It represents a kind of “environment“ around the setpoint within which the actual value may fluctuate. That means, we specify a minimum value that is lower than the setpoint, and a maximum value that is a little higher than the setpoint. Only if the actual value exceeds the maximum value or drops below the minimum value does the control system react. In most cases, the minimum and the maximum value are distanced from the setpoint equally; that is, the hysteresis generates a symmetrical environment around the set point.

In the case of the boiler water temperature, the burner would be switched on, for example, when the water temperature drops below the specified setpoint by more than a certain value. The burner continues to run until a certain value that is above the setpoint is exceeded. Only then will the burner be switched off. Another typical example is cooling. Usually, a cooler also does not support a continuous control system, but only knows the states “On“ and “Off“. It is switched on when the actual temperature exceeds the setpoint temperature by a few degrees, and is switched off when the actual temperature is a few degrees too low.

It is therefore typical for the two position controller to periodically fluctuate around the setpoint whose amplitude is roughly that of the hysteresis. The selection of the hysteresis depends on how exactly the setpoint has to be adhered to. If we select a large hysteresis, the actual value can deviate more considerably from the setpoint. If we select a smaller one, the setpoint is adhered to more exactly, but the system would have to switch more frequently. This again has its disadvantages, such as a higher wear of the switching devices, and the actuator or the final control element.

The diagram below shows a two position controller:



2.7.2 Three Position Controllers

The three position controllers represent the second important class of discrete controllers.
The difference regarding the two position controllers consists in the following: The controller output can handle three different values: positive influence, no influence, and negative influence of the controlled variable.
An example is control by means of a valve that can be adjusted electrically but that itself can only be completely open or completely closed. Let’s take, for example, water level control. As soon as the water level exceeds a maximum value, the valve motor is triggered with a positive direction of rotation, and the valve is opened. The control system remains inactive -that is, the motor is idle- until the water level drops below a minimum value. When this is the case, the motor is triggered into the negative direction of rotation, and the valve is closed. Thus the actuator knows three states: rotating valve motor with positive direction of rotation, idle motor, and rotating motor in negative direction of rotation.

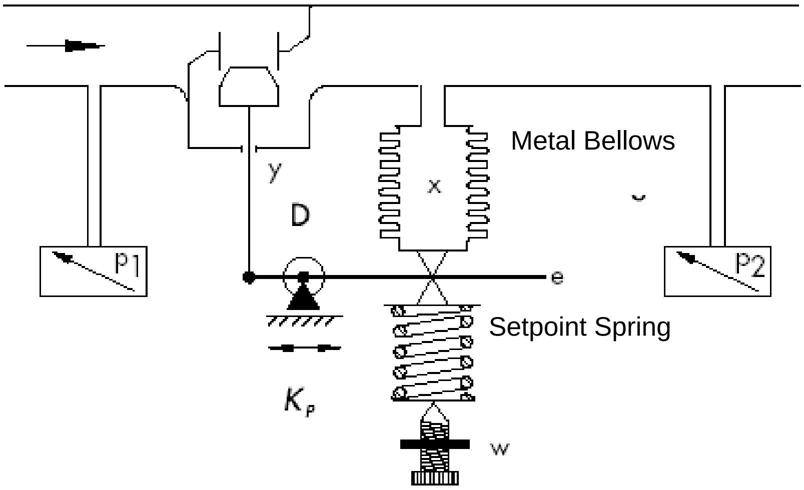
2.7.3 Basic Types of Continuous Controllers

The discrete controllers just discussed have, as mentioned before, the advantage of being simple. The controller itself as well as the actuator and the final control element are of a simpler nature and thus less expensive than for continuous controllers. However, discrete controllers have a number of disadvantages. If high loads, such as large electrical motors or cooling systems have to be operated, high peak loads can occur that can overload the power supply. For these reasons, we often don’t switch between “Off“ and “On“, but between a full load and a base load -with a clearly lower use of the actuator or final control element. But even with these improvements, a continuous controller is not suitable for many applications. Imagine a car engine whose speed is governed discretely. There would be nothing between idle and full throttle. Aside from it probably being impossible to transfer the power during a sudden full throttle suitably over the tires onto the road, such a car would probably be quite unsuitable for street traffic. For such applications, continuous controllers are used for that reason. Here, the mathematical relationship that the controlling element establishes between system deviation and controller output variable is theoretically virtually limitless. In practice, however, we differentiate among three classical basic types that are discussed in greater detail below.

2.7.3.1 Proportional Controllers (P-Controller)

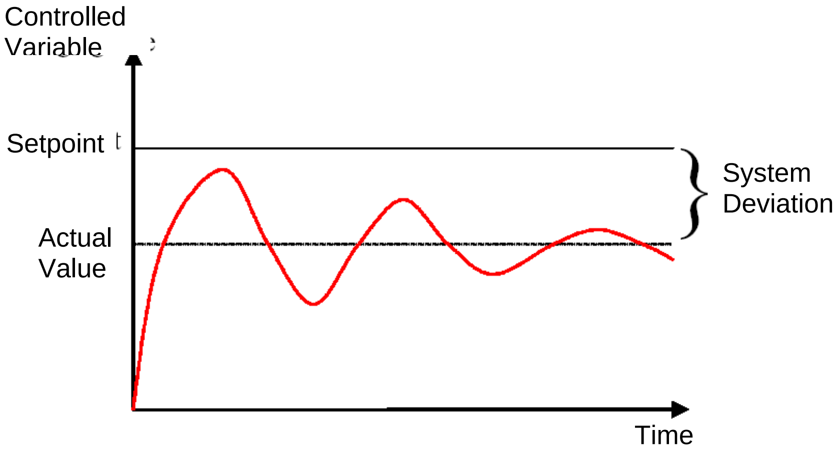
In the case of a P-controller, the controller output y is always proportional to the recorded system deviation (y ~ e). The result is that a P-controller responds to a system deviation without a delay, and generates a controller output only if there is a deviation e.

The proportional pressure regulator sketched in the figure below compares the force FS of the setpoint spring with the force FB that pressure p2 generates on the spring-elastic metal bellows. If the force is not in balance, the lever rotates around the pivot point D. The valve position ñ changes, and accordingly the pressure p2 to be controlled until a new power balance is established. The figure shows the behavior of the P-controller as a sudden system deviation occurs. The amplitude of the controller output step y depends on the extent of the system deviation e, and the amount of the proportional coefficient Kp: To keep the system deviation low, a proportional factor has to be selected that is as large as possible. Increasing the factor accelerates the reaction of the controller; however, a value that is too high may cause overshoot, and a considerable oscillatory tendency of the controller.



$$y = K_p \cdot e$$

The figure below shows the performance of the P-controller:



The advantages of this controller type are, on the one hand, its simplicity (the electronic implementation can, in the simplest case, consist of merely a resistor); on the other hand, in its prompt reaction in comparison to other controller types. The main disadvantage of a P-controller is its lasting system deviation. The setpoint is never completely reached, even over long periods of time. This disadvantage as well as a reaction speed that is not yet ideal can be minimized only insufficiently by using a larger proportional factor, since otherwise, the controller will overshoot; that is, it will overreact so to speak. In the worst case, the controller oscillates continuously, whereby the controlled variable is moved by the controller itself away from the setpoint -instead of by the disturbance variable.

The problem of continuous system deviation is best solved by the integral action controller.

2.7.3.2 Integral Action Controllers (I- Controller)

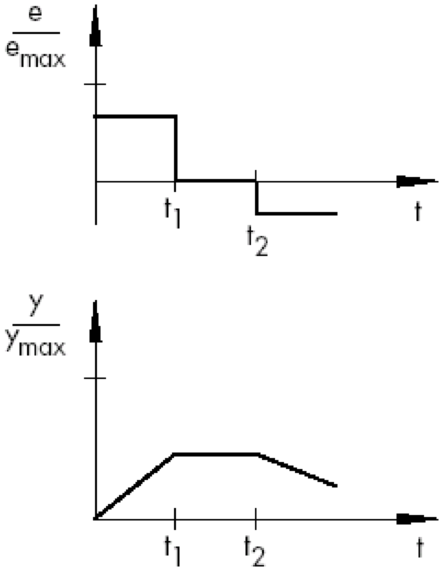
Integrating controllers are used to completely correct system deviations at every operating point. As long as the system deviation is not equal to zero, the amount of the controller output changes. Only when the reference variable and the controlled variable are equal -at the latest however, when the controller output reaches its system-dependent limit (Umax, Pmax etc.)- is the controller in a steady state.

The mathematical formula for this integral action is:

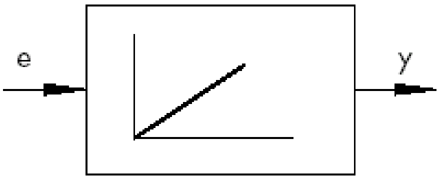
The controller output is proportional to the time integral of the system deviation:

$$y = K_i \int e \, dt \qquad \textbf{\textit{with}}: K_i = \frac{1}{T_n}$$

How fast the controller output rises (or falls), depends on the system deviation and the integration time.

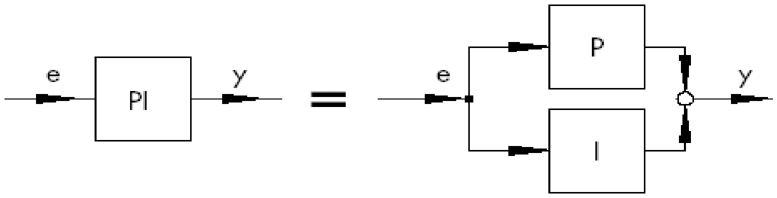


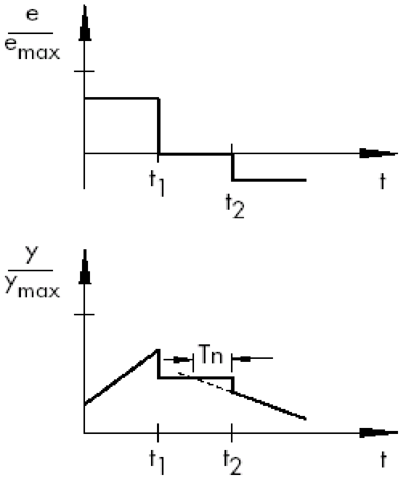
Block Diagram



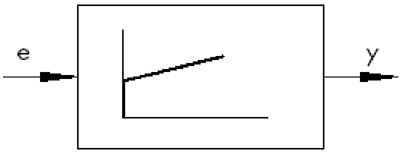
2.7.3.3 PI Controllers

In practice, the PI controller is a controller type that is used very often. It consists of the parallel connection of a P-controller and an I-controller. When laid out correctly, it combines the advantages of both controller types (stable and fast, no lasting system deviation), so that their disadvantages are compensated for at the same time.





Block Diagram



The trend is indicated with the proportional coefficient Kp and the reset time Tn. Based on the proportional component, the controller output responds immediately to each system deviation e, while the integral component has an effect only in the course of time. Tn represents the time that passes until the I-component generates the same margin of the manipulated variable as it is generated immediately because of the P-component (Kp). As for the I-controller, the reset time Tn has to be reduced if you want to increase the integral component.

Controller Layout:

Depending on the Kp and Tn dimensioning, the overshoot of the controlled variable can be reduced at the expense of control system dynamics.

Applications for the PI controller: fast control loops that don’t permit lasting system deviations.

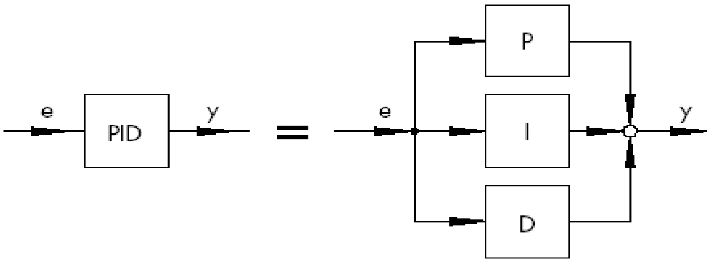
Examples: pressure, temperature, ratio control.

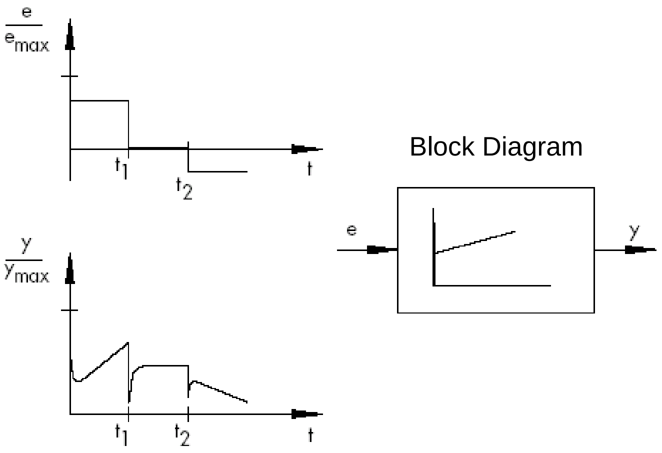
2.7.3.4 Derivative Action Controllers (D-Controller)

The D-controller generates its controller output from the rate of change of the system deviation, and not -like the P-controller- from its amplitude. For that reason, it still responds considerably faster than the P-controller. Even if the system deviation is small, it generates -in anticipation, as it were- large margins of the manipulated variable as soon as the amplitude changes. On the other hand, the D-controller does not know a lasting system deviation; because, regardless of how large it is, its rate of change equals zero. In practice, the D-controller is used rarely by itself for that reason. Rather, it is used together with other control elements, usually in connection with a proportional component.

2.7.3.5 PID Controllers

If we expand a PI controller with a D-component, we enhance the universal PID controller. As in the case of the PD controller, adding the D-component has the effect that, if laid out correctly, the controlled variable reaches its setpoint sooner and enters the steady state faster.





$$y = K_p \cdot e + K_i \int e\,dt + K_D \frac{de}{dt} \ \textbf{\textit{with}}\ t\, K_i = \frac{K_p}{T_n};\ K_D = K_p \cdot T_V$$

2.8 Objectives for Controller Adjustment

For a satisfactory control result, selecting a suitable controller is an important aspect. However, even more important is the setting of the suitable controller parameters Kp, Tn and Tv that have to be adjusted to the controlled system behavior. Usually, a compromise has to be made between a very stable but also slow controller, or a very dynamic, more unstable controlled system performance, which, under certain circumstances, tends to oscillate and can become unstable.
In the case of non-linear systems that are always to work at the same operational point -for example, fixed setpoint control- the controller parameters have to be adjusted to the controlled system behavior at this working point. If, as in the case of cascaded controls ñ, no fixed working point can be defined, a controller adjustment has to be found which provides a sufficiently fast and stable control result over the entire work area.
In practice, controllers are usually set based on empirical values. If none are available, the controlled system behavior has to be analyzed exactly, in order to subsequently specify suitable controller parameters, with the aid of different theoretical or practical layout procedures.

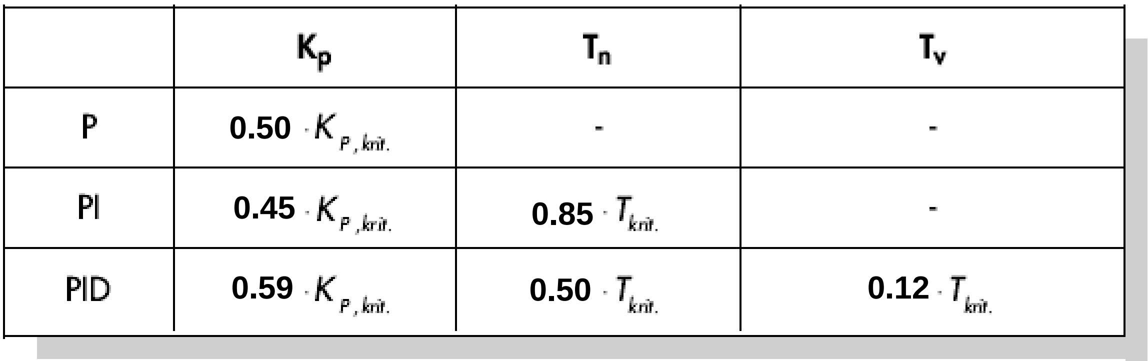
One possibility of a definition is the oscillation test according to the
Ziegler-Nichols method. It offers a simple layout suitable for many cases. However, this setting procedure can only be used for controlled systems that permit getting the controlled variable to oscillate autonomously. The following has to be done:

- Set Kp and Tv at the controller to the lowest value, and Tn to the highest value (the lowest possible controller effect).
- Take the controlled system manually to the desired operating point (start the controller).
- Set the manipulated variable of the controller manually to the specified value, and switch to the automatic mode.
- Increase Kp (decrease Xp) until harmonic oscillations can be recognized in the controlled variable. If possible, the control loop should be stimulated to oscillate during the Kp setting by using small, abrupt setpoint changes.

- Note down the Kp value that has been set as the critical proportional coefficient.

- Specify the duration of a complete oscillation as Tkrit, perhaps with a stop watch by generating the arithmetical mean over several oscillations.

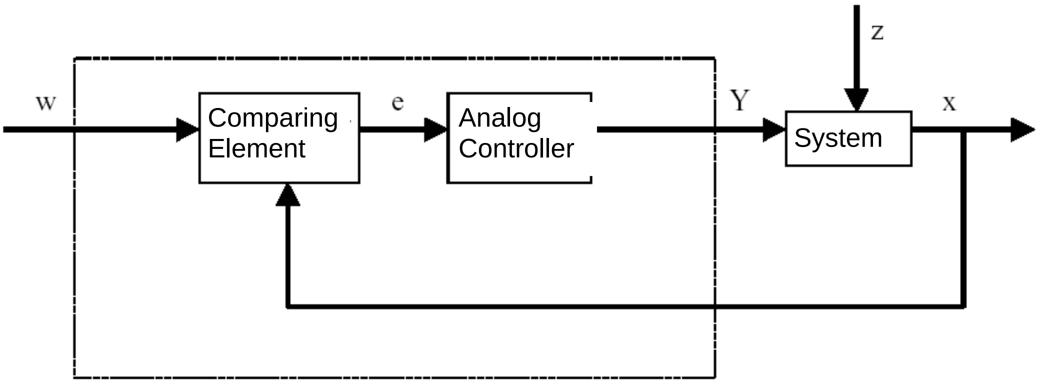
- Multiply the values of Kp,krit and Tkrit with the multipliers according to the table, and thus set the determined values for Kp, Tn and Tv at the controller.



	K_p	T_n	T_v
P	$0.50 \cdot K_{P,krit.}$	-	-
PI	$0.45 \cdot K_{P,krit.}$	$0.85 \cdot T_{krit.}$	-
PID	$0.59 \cdot K_{P,krit.}$	$0.50 \cdot T_{krit.}$	$0.12 \cdot T_{krit.}$

2.9 Digital Controllers

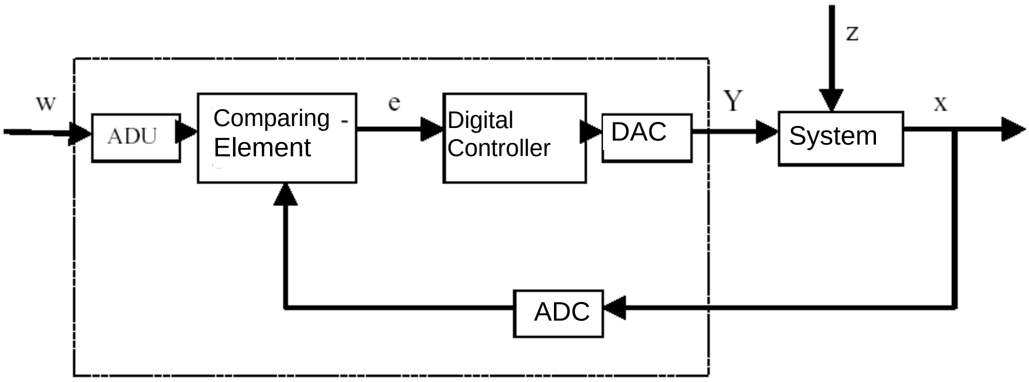
So far, mainly analog controllers were discussed; that is, such controllers that derive the controller output variable -also in an analog way- from the existing system deviation that exists as analog value. We are already familiar with the diagram of such a control loop:



Often, however, it has its advantages to evaluate the system deviation digitally. On the one hand, the relationship between system deviation and controller output variable has to be specified much more flexibly if it is defined through an algorithm or a formula with which a computer can be programmed respectively, as when it has to be implemented with an analog circuit. On the other hand, a clearly higher integration of circuits is possible in digital engineering, so that several controllers can be accommodated in the smallest space. And finally, by dividing the computing time it is even possible -if the computing capacity is sufficiently large- to use a single computer as controlling elements of several control loops.

To make digital processing of the variables possible, the reference variable as well as the feedback variable have to first be converted in an analog-digital converter (ADC) into digital variables. These are then subtracted from each other by a digital comparing element, and the difference is transferred to the digital controlling element. Its controller output variable is then converted again in a digital-analog converter (DAC) into an analog variable. The unit consisting of converters, comparing element, and controlling element appears to the outside like an analog controller.

The diagram below shows the layout of a digital controller:



However, the digital conversion of the controller has not only advantages; this conversion also entails various problems. For that reason, some variables have to be selected sufficiently large in reference to the digital controller so that the accuracy of the control does not suffer too much on account of digitalization. Quality criteria for digital computers are:

- The quantization resolution of the digital-analog converters.

It indicates how fine the continuous value range is digitally rasterized. The resolution has to be selected of a size that no resolutions important to the controller are lost. .

- The scanning frequency of the analog-digital converters.

This is the frequency with which the analog values pending at the converter are measured and digitalized. This has to be high enough that the controller can still respond in time if the controlled variable suddenly changes.

- The cycle time

In clock cycles, every digital computer processes differently than the analog computer. The speed of the computer used has to be high enough that during a clock cycle (during which the output value is calculated, and no input value is scanned), the controlled variable can not change significantly.
The quality of the digital controller has to be high enough so that toward the outside, it responds comparably prompt and precise, like an analog controller does.

3. DISCONTINUOUS ACTION CONTROLLER AS TWO POSITION CONTROLLER

3.1 Function and Problem Description

A process value (for example, the level) is to be kept as constant as possible with a discontinuous action controller.
The output voltage at a digital output of the PLC generates the manipulated variable y which can be set either to "ON" (voltage =24V) or "OFF" (voltage =0V).
The process value represents the controlled variable x, which is suitably recorded with a measuring sensor (PEW XY).
It is the controller’s task to keep the controlled variable X constant at a specified setpoint, whereby the influence of disturbance variables z that can not be anticipated is to be eliminated. The PLC S7-300 is used for this task as discontinuous action controller. The S7-300 is to solve the control problem by reading out a binary manipulated variable y depending on the respective setpoint/actual comparison w-x.
To prevent valve V1 from constantly being switched on and off when the controlled variable x has reached the setpoint w, a switching hysteresis is installed for discontinuous action controllers. Because of the switching hysteresis, the controlled variable x oscillates between a high response value Xo and a low response value Xu. The difference between the high response value Xo and the low response value Xu is called differential Xs = Xo - Xu.
Xs is often specified depending on the amount of setpoint w.
For example, 10% of setpoint w: Xs = w/10.

In this program, a two position controller can be switched on with the button “Start“ to fill a tank. With the button “Stop“, the controller can be switched off. The tank is filled by means of a pump that can be triggered digitally. The setpoint is specified via a potentiometer at the analog input "AI_Fill_Setpoint“.

In a subroutine, the analog value for the process variable Level is to be entered, and normalized to the physical variable "Liter“. The normalized value is made available as floating point number in MD20.
For a level of 10 liters, the level sensor returns 0V, for 100 liters 10V.
The analog value for the setpoint is also to be entered here, and made available as floating point number in MD24.

If the controller is switched on, the lamp "Display_ON“ is to light up.

Below, the structogram for the program of the step controller is provided.

Structogram

A structogram shows the rough structure of a program plan. The structogram below shows the possible structure of a program for a two position controller.
First, a scan is made whether the controller is switched on.
If it is switched off, only the program is executed in which the outputs and flags are reset.
From the program-engineering view, this is done most simply by means of jump instructions.
If the controller is switched on, the setpoint and actual value are entered, and the calculations for switching hysteresis, differential and the lower operating point are made.
Then, another scan follows: whether the actual value is below the low operating point.
If this is the case, the controller output is switched on, and a jump is made to the end of the program.
If this is not the case, the high operating point is calculated, and a scan is made whether the actual value is above the high operating point.
Then, again a jump is made to the end of the program.

<table>
<tr><td colspan="4">Controller switched off?</td></tr>
<tr><td>YES</td><td colspan="3">NO</td></tr>
<tr><td rowspan="10">Outputs
and
Flags
Clear
or
Reset</td><td colspan="3">Display: Switch on SH10
Enter actual value x and
setpoint w
Normalize</td></tr>
<tr><td colspan="3">Calculation of the switching hysteresis Xs = w/10</td></tr>
<tr><td colspan="3">Calculation of half the differential X1 = Xs/2</td></tr>
<tr><td colspan="3">Calculation of the low operating point Xu = w - X1</td></tr>
<tr><td colspan="3">Is the actual value less than the low operating point?</td></tr>
<tr><td>YES</td><td colspan="2">NO</td></tr>
<tr><td rowspan="4">Pump ON</td><td colspan="2">Calculation of the high operating point Xo = w + X1</td></tr>
<tr><td colspan="2">Actual value X larger than Xo?</td></tr>
<tr><td>YES</td><td>NO</td></tr>
<tr><td>Pump OFF</td><td></td></tr>
</table>

Assignment List:

Symbol:	**Address:**	**Comment**
Start	I 1.3	Button Start
Stop	I 1.4	Button Stop
AI_Level_Actual	PEW 128	Analog input for the level sensor
AI_Level_Setpoint	PEW 130	Analog input for the setpoint selection
AI_Level_Act_Norm	MD 20	Normalized value for the level
AI_Level_Setp_Norm	MD 24	Normalized value for the level setpoint
M_X1	MD 32	Intermediate flag half the differential
M_Xo	MD 36	Intermediate flag high operating point
M_Xs	MD 28	Intermediate flag switching hysteresis
M_Xu	MD 40	Intermediate flag low operating point
Controller_On	M 10.0	Flag controller is switched on
Pump	A 0.0	Pump activation binary
Display_ON	A 1.0	Indication: system is on
Analog	FC1	Subroutine analog value processing
Two Pos.Controller	FC2	Subroutine two position controller

Exercise:

Create a project with hardware configuration for a CPU314C-2 DP (refer to Module A05) and change the addresses according to the assignment list shown above.

There, create a program in an FC1 with the following functionality:
- The analog value for the process variable Level is to be entered, and normalized to the physical variable "Liter“. The normalized value is made available in MD20 as a floating point number.

Note: If the level is 10 liters, the level sensor returns 0V, for 100 liters 10V.
- The analog value for the setpoint is to be entered, and made available normalized as floating point number in MD24.
Save FC1.

Then, set up the two position controller in an FC2, based on the structogram provided above.
Call FC1 for inputting the setpoint and the actual value.

Save FC2 and call it in OB1. Save OB1 and load the entire station to the PLC.

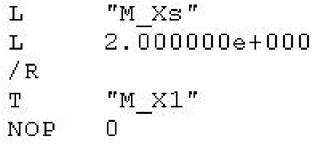
3.2 Possible Solution for the PLC Program:

```
FC1 :Analog Value Processing
Network 1:    Enter and normalize analog value of actual level
        L      "AI_Level_Actual“
        ITD
        DTR
        L      2.764800e+004
        /R
        L      9.000000e+001
        *R
        L      1.000000e+001
        +R
        T      "AI_Level_Actual_Norm“


Network 2:    Enter and normalize analog value of setpoint level
        L      "AI_Level_Setp“
        ITD
        DTR
        L      2.764800e+004
        /R
        L      9.000000e+001
        *R
        L      1.000000e+001
        +R
        T      "AI_Level_Setp_Norm“
```

****

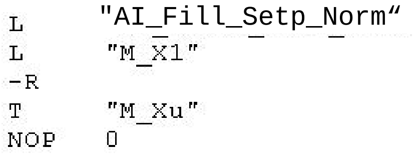
```
FC2 Two Position Contoller
Network 1: Controller switched on?? If off, then jump to label "Off“

        U      "Start“
        S      "Controller_On“
        UN     "Stop“
        R      "Controller_On“
        U      "Controller_On“
        =      "Ind_ON“
        SPBN   exit

Network 2: Call subroutine: enter and normalize analog values

        CALL   "Analog"
        NOP    0

Network 3: Calculation of switching hysteresis Xs = w/10
        L      "AI_Fill_Setp_Norm“
        L      1.000000e+001
        /R
        T      "M_Xs"
        NOP    0
```

Network 4: Calculation of half differential X1 = Xs/2



```
L     "M_Xs"
L     2.000000e+000
/R
T     "M_X1"
NOP   0
```

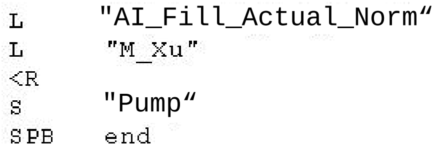
Network 5: Calculation of the low operating point Xu = w – X1



```
L     "AI_Fill_Setp_Norm“
L     "M_X1"
-R
T     "M_Xu"
NOP   0
```

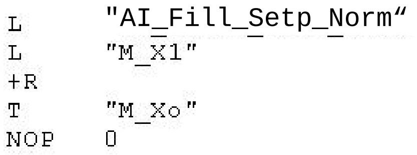
Network 6: ACTUAL VALUE x less than low operating point?

MD24/AI_Fill_Setp_Norm/Norm.value for level setpoint



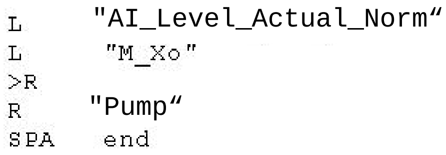
```
L     "AI_Fill_Actual_Norm“
L     "M_Xu"
<R
S     "Pump“
SPB   end
```

Network 7: Calculation of the high operating point Xo = w – X1



```
L     "AI_Fill_Setp_Norm“
L     "M_X1"
+R
T     "M_Xo"
NOP   0
```

Network 8: Actual value X larger than Xo?



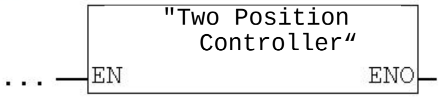
```
L     "AI_Level_Actual_Norm“
L     "M_Xo"
>R
R     "Pump“
SPA   end
```

```
      Network 9:  Reset values
exit:      L      0.000000e+000
           T      "AI_Fill_Actual_Norm"
           T      "AI_Fill_Setp_Norm
           T      "M_Xs"
           T      "M_X1"
           T      "M_Xo"
           T      "M_Xu"
           U      "Pump"
           R      "Pump"
           U      "Display_ON"
           R      "Display_ON"
           SPA    end

      Network 10:  Title
end:       NOP    0
```

****

OB1: Title

Network 1: Call subroutine: Two position controller



4. CONTROLLER BLOCK (S)FB41 "CONT_C" AS SOFTWARE PID CONTROLLER IN STEP 7

4.1 Task Definition for PID Standard Controller

In this B3 module, the startup of a PID controller in SIMATIC S7 is demonstrated. The output value of the controlled system is to be kept constant with a continuous controller. Depending on the setting, the controlled system can simulate a P, PT1, or PT2 system. The transfer coefficients Ks and the time constants can also be set. (refer to the description of the controlled system).

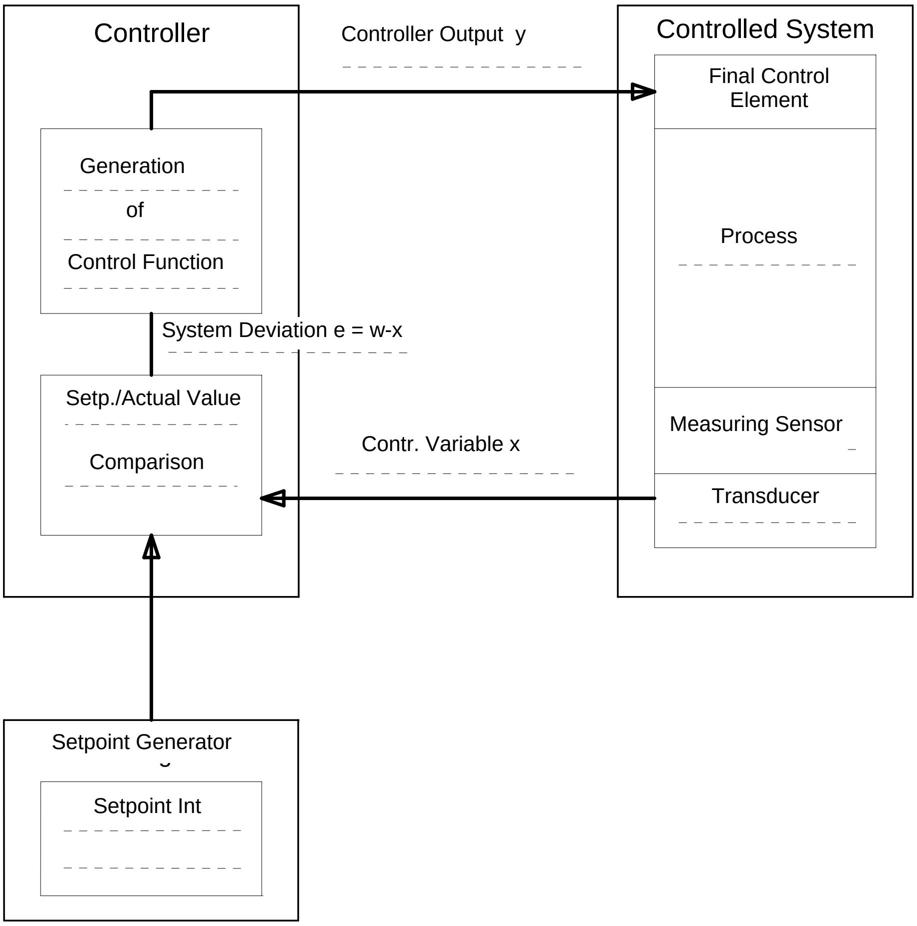
Thus, the PLC is the controller, and is connected to the controlled system by means of analog inputs and outputs.
The block (S)FB 41 in the PLC SIMATIC S7-300 is used in this task as a continuous digital software controller. It is to solve the control problem as follows: an analog manipulated variable y is read out depending on the respective setpoint/actual value w-x. The manipulated variable y is generated according to the PID algorithm.
The following control parameters can be specified:

KP: Proportional component (for (S)FB41 Gain)
TN: Integrator time (for (S)FB41 TI)
TV: Derivative time (for (S)FB41 TD)

Assignment List:

Symbol:	**Address:**	**Comment**
AI_w	PEW 128	Analog input setpoint generator 0…10V
AI_X	PEW 130	Analog input sensor actual value 0…10V
AO_Y	PAW 128	Analog output manipulated variable 0 … 10V
M_w	MD40	Internal setpoint (floating point number normalized)

Function Diagram of the control system with a PID controller



4.2 (S) FB 41 “CONT_C“

(S)FB 41 "CONT_C“ (continuous controller) is used for controlling technical processes with continuous input and output variables on the PLC SIMATIC S7. By means of parameter assignments, you can switch on or switch off subfunctions of the PID controller, and thus adjust it to the controlled system.

Use:

You can use the controller as PID fixed setpoint controller individually, or in multi-loop control systems as cascade controller, blended controller, or ratio controller. The working method is based on the PID algorithm of the sampling controller with analog output signal; if needed, supplemented with a pulse shaper step to generate pulse-width-modulated output signals for two position or three position controller with proportional final control elements.

Description:

In addition to the functions in the setpoint and actual value, the (S)FB implements a complete PID controller with a continuous manipulated variable output and the capability to influence the manipulated value manually.
Depending on the CPU type, it can be used as FB 41 or as SFB 41.

The following subfunctions exist:

- *Setpoint branch*
- *Actual value branch*
- *System deviation generation*
- *PID algorithm*
- *Manual value processing*
- *Manipulated value processing*
- *Feedforward control*

Operating modes complete restart/restart

The (S)FB 41 (CONT_C) has a complete restart routine that is run if the input parameter is set to COM_RST = TRUE.
At startup, the integrator is set internally to the initialization value I_ITVAL. When called in a time interrupt level, it continues processing starting with this value.
The other outputs are set to their default values.

Error Information

The error signal word RET_VAL is not used.

Starting Up the Software PID Controller (S)FB41 "CONT_C" with STEP 7

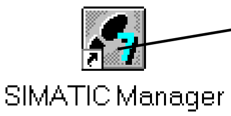
A SIMATIC S7-300 is programmed as a PID controller with the software STEP 7. This provides the user with a uniform configuring tool for central as well as distributed configurations. Here, only the most essential aspects can be pointed out. (Additional information is provided in the STEP7 reference manuals.)

The PID controller is parameterized with a special application included in STEP7 -**Assigning parameters to a PID Control-** by resetting values there in an instance DB associated with the (S)FB 41. This is done as follows:

4.3 Exercise Example

The user has to perform the steps below in order to configure the hardware as well as to generate an S7 program with the functionality of a PID controller, and then load it to a PLC:

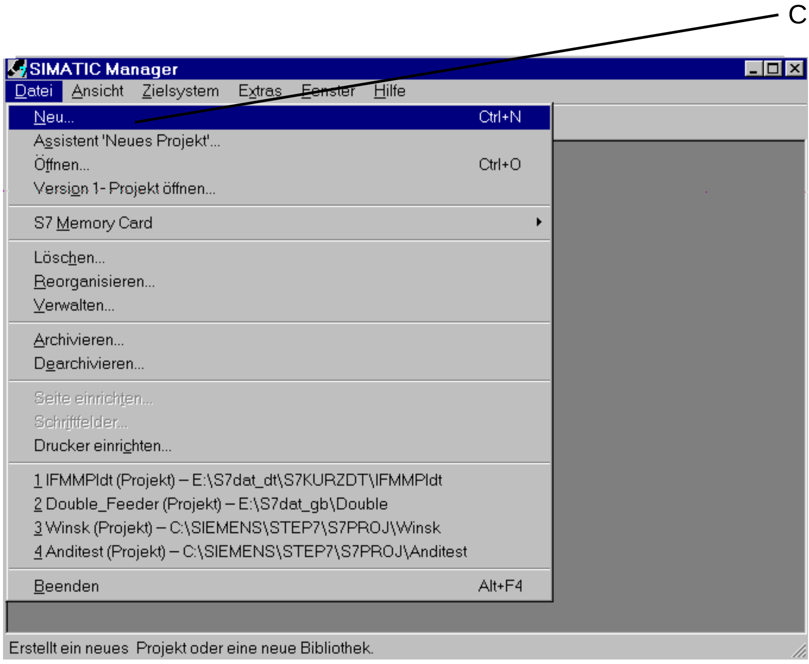
1. Call the SIMATIC Manager



Click on symbol 'SIMATIC Manager'

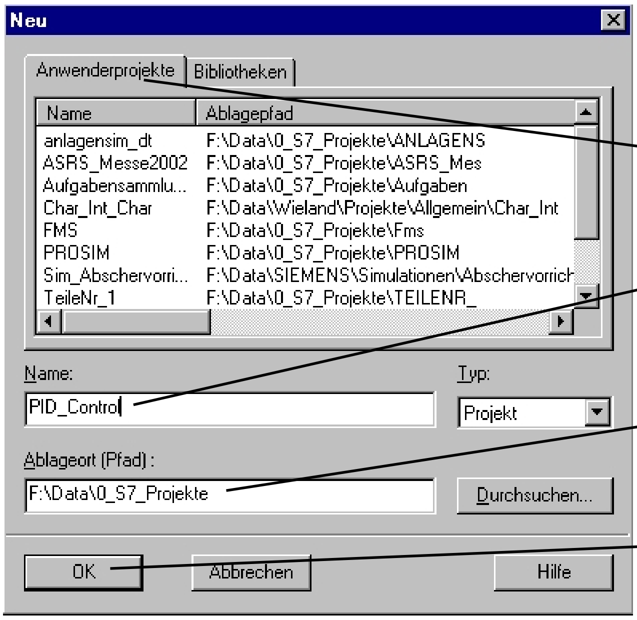
2. Set up new project (→ File → New)

Click on 'New'


SIMATIC Manager
Datei
Ansicht
Zielsystem
Extras
Fenster
Hilfe
Neu... Ctrl+N
Assistent 'Neues Projekt'...
Öffnen... Ctrl+O
Version 1- Projekt öffnen...
S7 Memory Card
Löschen...
Reorganisieren...
Verwalten...
Archivieren...
Dearchivieren...
Seite einrichten...
Schriftfelder...
Drucker einrichten...
1 IFMMPldt (Projekt) – E:\S7dat_dt\S7KURZDT\IFMMPldt
2 Double_Feeder (Projekt) – E:\S7dat_gb\Double
3 Winsk (Projekt) – C:\SIEMENS\STEP7\S7PROJ\Winsk
4 Anditest (Projekt) – C:\SIEMENS\STEP7\S7PROJ\Anditest
Beenden Alt+F4

Erstellt ein neues Projekt oder eine neue Bibliothek.

3. Generate a new project, select a path and assign a project name (→ User projects → PID_Control → OK)



Name	Ablagepfad
anlagensim_dt	F:\Data\0_S7_Projekte\ANLAGENS
ASRS_Messe2002	F:\Data\0_S7_Projekte\ASRS_Mes
Aufgabensammlu...	F:\Data\0_S7_Projekte\Aufgaben
Char_Int_Char	F:\Data\Wieland\Projekte\Allgemein\Char_Int
FMS	F:\Data\0_S7_Projekte\Fms
PROSIM	F:\Data\0_S7_Projekte\PROSIM
Sim_Abschervorri...	F:\Data\SIEMENS\Simulationen\Abschervorrich
TeileNr_1	F:\Data\0_S7_Projekte\TEILENR_

Name: PID_Control

Typ: Projekt

Ablageort (Pfad): F:\Data\0_S7_Projekte

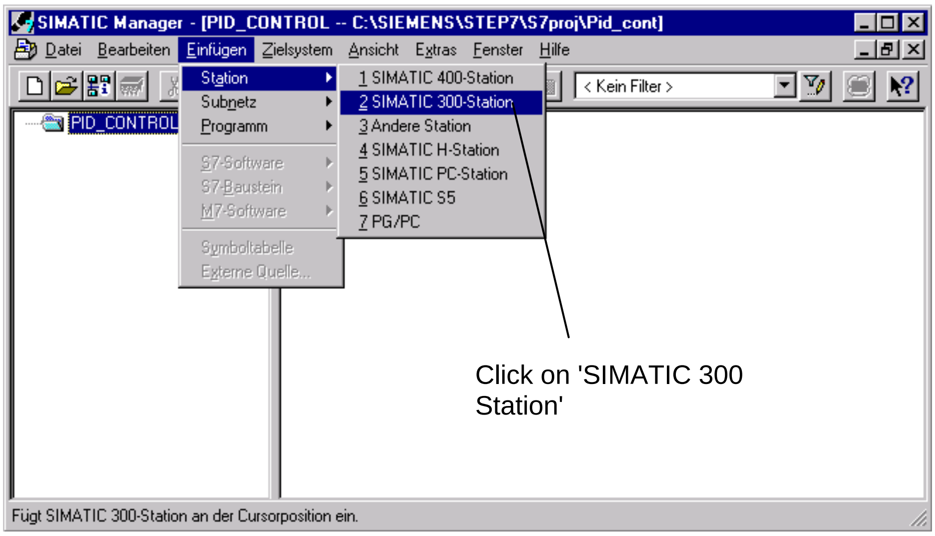
Select 'User Projects'

Enter project name

Select storage location (path)

Cick 'OK'

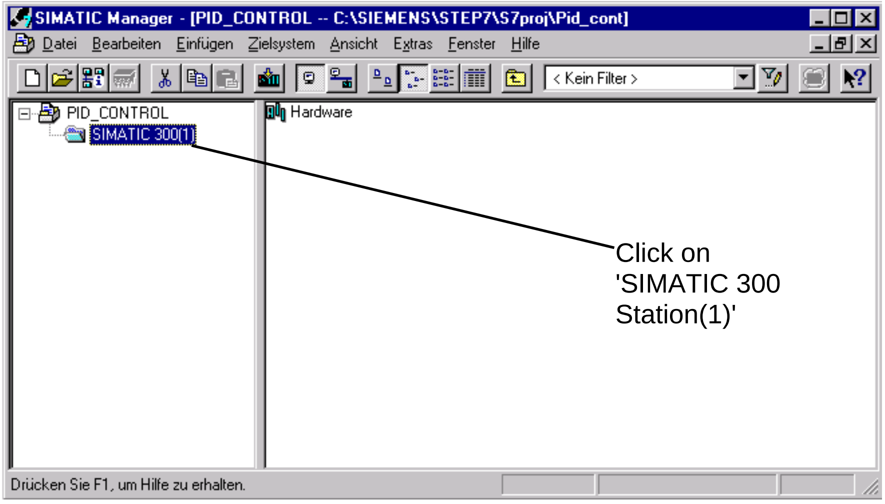
4. Insert the SIMATIC 300 station (→ Insert → Station → SIMATIC 300 Station)



Fügt SIMATIC 300-Station an der Cursorposition ein.

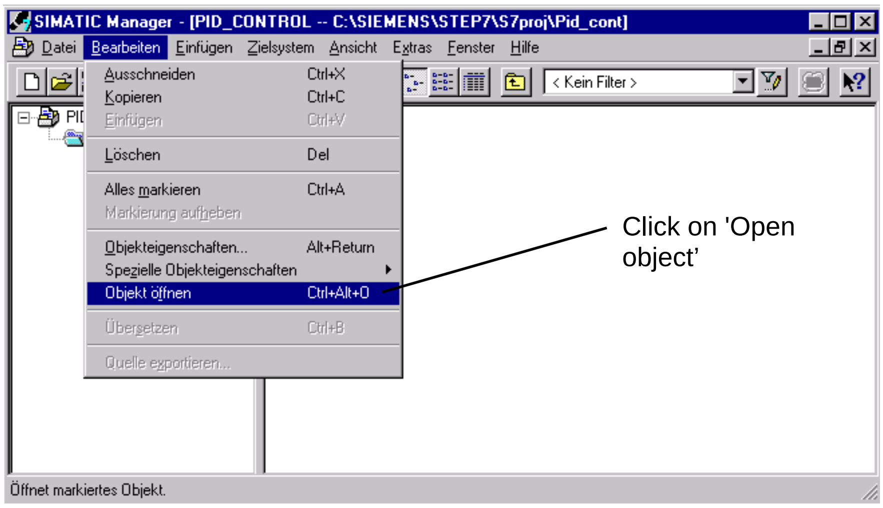
Click on 'SIMATIC 300 Station'

5. Highlight 'SIMATIC 300 Station(1)'.


SIMATIC Manager - [PID_CONTROL -- C:\SIEMENS\STEP7\S7proj\Pid_cont]
Datei Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
< Kein Filter >
PID_CONTROL
SIMATIC 300(1)
Hardware
Drücken Sie F1, um Hilfe zu erhalten.

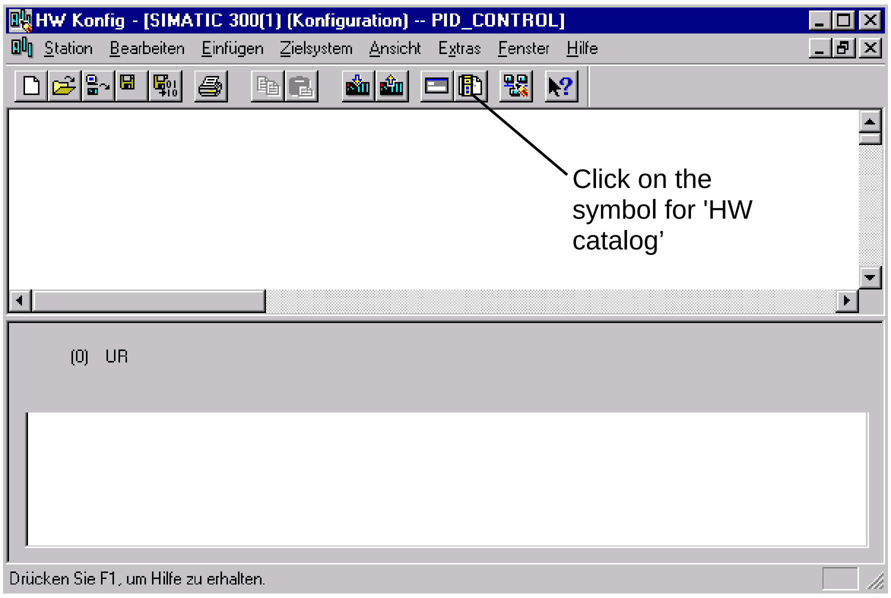
Click on 'SIMATIC 300 Station(1)'

6. Open configuring tool for the hardware configuration (→ Edit → Open object)


SIMATIC Manager - [PID_CONTROL -- C:\SIEMENS\STEP7\S7proj\Pid_cont]
Datei Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
< Kein Filter >
PID
Ausschneiden Ctrl+X
Kopieren Ctrl+C
Einfügen Ctrl+V
Löschen Del
Alles markieren Ctrl+A
Markierung aufheben
Objekteigenschaften... Alt+Return
Spezielle Objekteigenschaften
Objekt öffnen Ctrl+Alt+O
Übersetzen Ctrl+B
Quelle exportieren...
Öffnet markiertes Objekt.

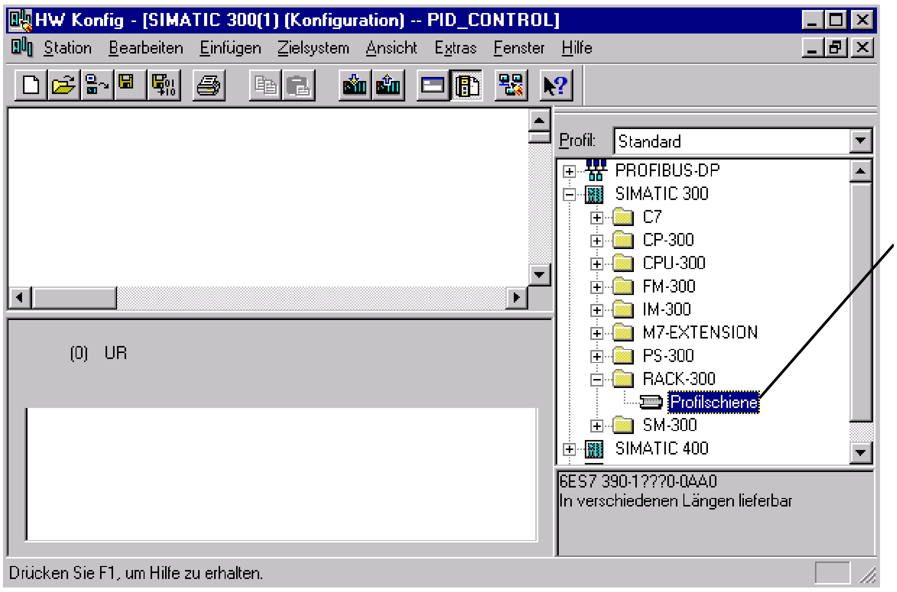
Click on 'Open object'

7. Open the hardware catalog.
Here, all racks, modules, and interface modules for configuring your hardware, are provided arranged in the directories: PROFIBUS-DP, SIMATIC 300, SIMATIC 400 and SIMATIC PC Based Control.


HW Konfig - [SIMATIC 300(1) (Konfiguration) -- PID_CONTROL]
Station Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
(0) UR
Drücken Sie F1, um Hilfe zu erhalten.

Click on the symbol for 'HW catalog'

8. Insert mounting channel (→ SIMATIC 300 → RACK-300 → Mounting channel).

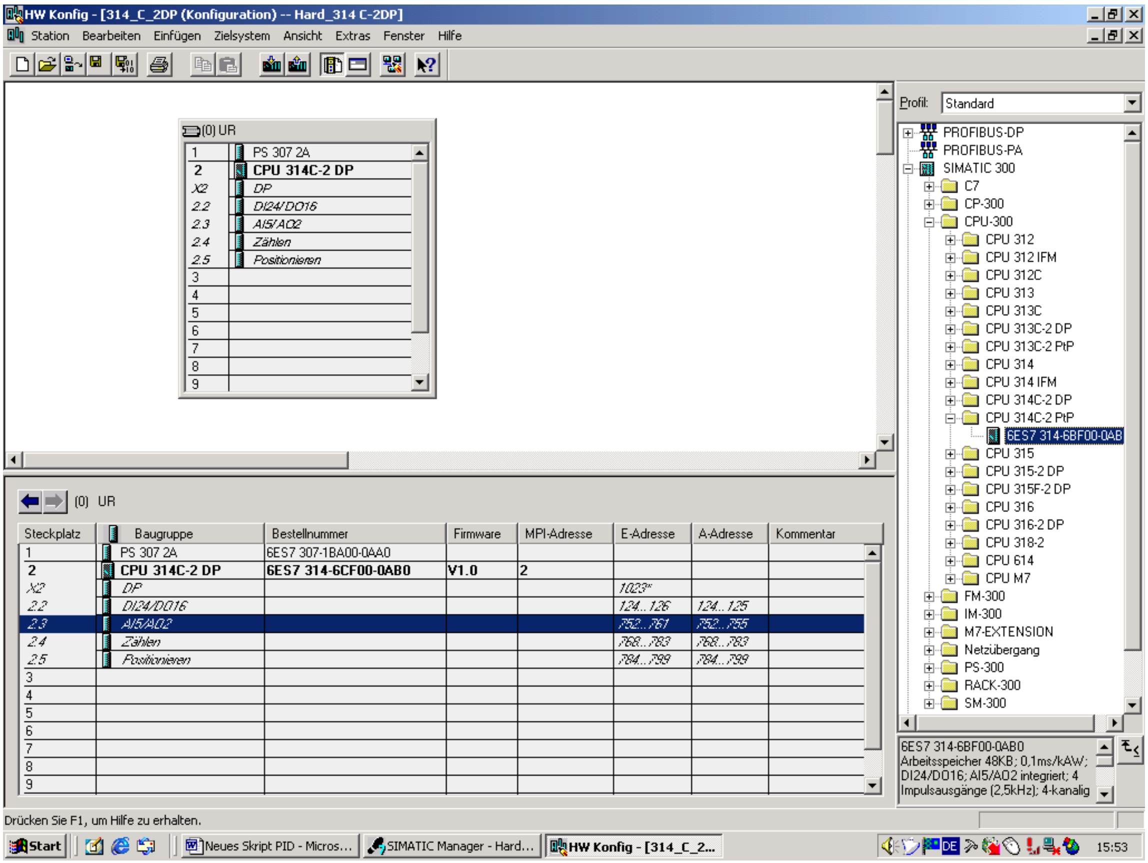

HW Konfig - [SIMATIC 300(1) (Konfiguration) -- PID_CONTROL]
Station Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
(0) UR
Profil: Standard
PROFIBUS-DP
SIMATIC 300
C7
CP-300
CPU-300
FM-300
IM-300
M7-EXTENSION
PS-300
RACK-300
Profilschiene
SM-300
SIMATIC 400
6ES7 390-1???0-0AA0
In verschiedenen Längen lieferbar
Drücken Sie F1, um Hilfe zu erhalten.

Click on 'Mounting channel'

Then a configuration table is displayed automatically for configuring Rack 0.

9. From the hardware catalog, all modules that are plugged inserted in your real rack can now be selected and inserted in the configuration table. To this end, you have to click on the name of the respective module, hold the mouse key and drag the module to a line in the configuration table.

Note: Slot 3 is reserved for interface modules, and remains empty for that reason.



(0) UR

1	PS 307 2A
2	CPU 314C-2 DP
X2	DP
2.2	DI24/DO16
2.3	AI5/AO2
2.4	Zählen
2.5	Positionieren
3	
4	
5	
6	
7	
8	
9	

(0) UR

Steckplatz	Baugruppe	Bestellnummer	Firmware	MPI-Adresse	E-Adresse	A-Adresse	Kommentar
1	PS 307 2A	6ES7 307-1BA00-0AA0					
2	CPU 314C-2 DP	6ES7 314-6CF00-0AB0	V1.0	2			
X2	DP				1023*		
2.2	DI24/DO16				124...126	124...125	
2.3	AI5/AO2				752...761	752...755	
2.4	Zählen				768...783	768...783	
2.5	Positionieren				784...799	784...799	
3							
4							
5							
6							
7							
8							
9							

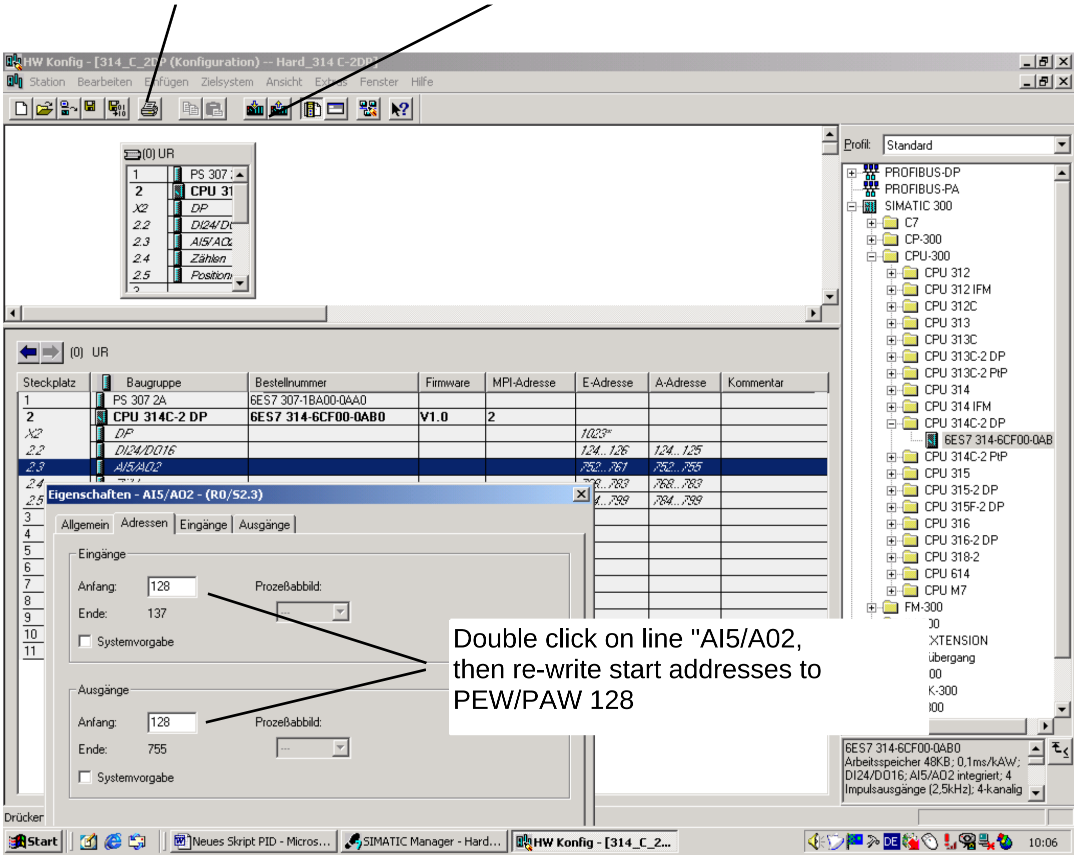
6ES7 314-6BF00-0AB0
Arbeitsspeicher 48KB; 0,1ms/kAW; DI24/DO16; AI5/AO2 integriert; 4 Impulsausgänge (2,5kHz); 4-kanalig

Drücken Sie F1, um Hilfe zu erhalten.

10. Note down the addresses of the IO modules *(addresses* are *assigned* automatically and *tied to the slot*).
For our example, change the addresses to the values PEW 128 and PAW 128.
Save the configuration table and load it to the PLC (key switch on CPU has to be on Stop!)

Click on symbol 'Save and convert'

Click on symbol 'Load to AS'



(0) UR

Steckplatz	Baugruppe	Bestellnummer	Firmware	MPI-Adresse	E-Adresse	A-Adresse	Kommentar
1	PS 307 2A	6ES7 307-1BA00-0AA0					
2	**CPU 314C-2 DP**	**6ES7 314-6CF00-0AB0**	**V1.0**	**2**			
X2	*DP*				*1023**		
2.2	*DI24/DO16*				*124...126*	*124...125*	
2.3	*AI5/AO2*				*752...761*	*752...755*	
2.4					*..783*	*768...783*	
2.5					*..799*	*784...799*	
3							
4							
5							
6							
7							
8							
9							
10							
11							

Eigenschaften - AI5/AO2 - (R0/S2.3)

Allgemein | Adressen | Eingänge | Ausgänge

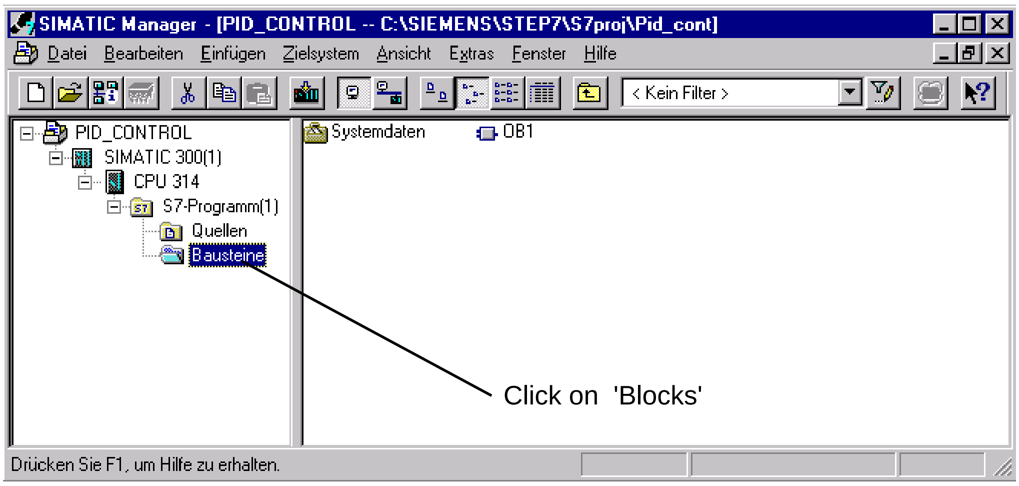
Eingänge
Anfang: 128 Prozeßabbild: ---
Ende: 137
□ Systemvorgabe

Ausgänge
Anfang: 128 Prozeßabbild: ---
Ende: 755
□ Systemvorgabe

6ES7 314-6CF00-0AB0
Arbeitsspeicher 48KB; 0,1ms/kAW; DI24/DO16; AI5/AO2 integriert; 4 Impulsausgänge (2,5kHz); 4-kanalig

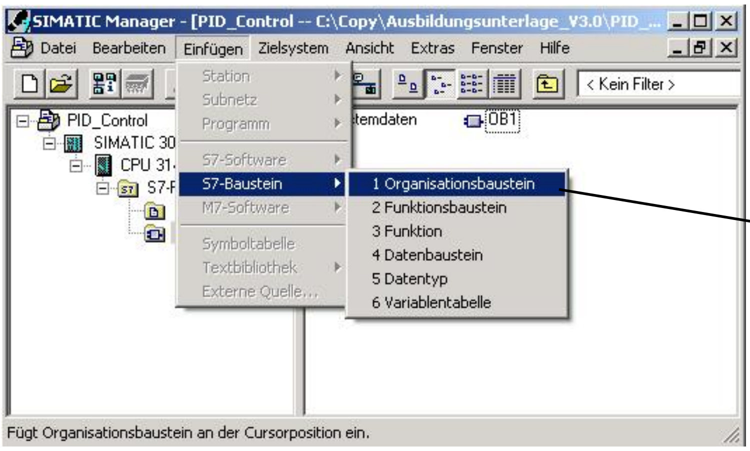
Double click on line "AI5/A02, then re-write start addresses to PEW/PAW 128

11. Highlight Blocks in SIMATIC Manager


SIMATIC Manager - [PID_CONTROL -- C:\SIEMENS\STEP7\S7proj\Pid_cont]
Datei Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
< Kein Filter >
PID_CONTROL
SIMATIC 300(1)
CPU 314
S7-Programm(1)
Quellen
Bausteine
Systemdaten
OB1
Drücken Sie F1, um Hilfe zu erhalten.

Click on 'Blocks'

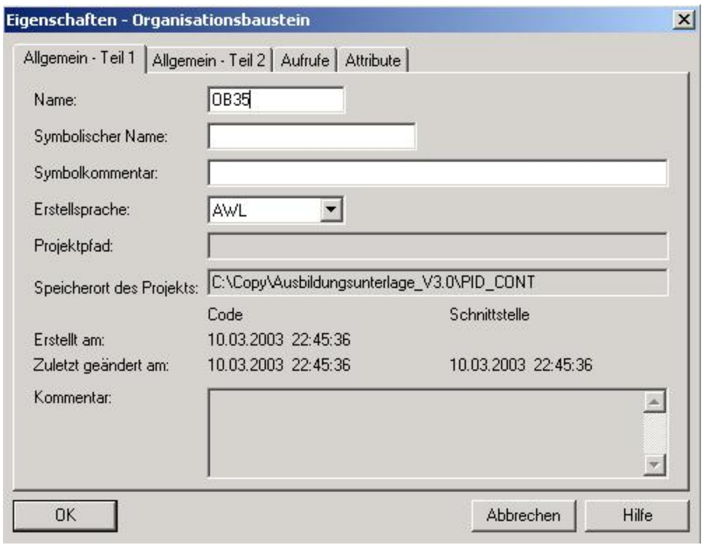
12. Insert organization block. (→ Insert → S7 Block → Organization block)



Fügt Organisationsbaustein an der Cursorposition ein.

Click on 'Organization block'

13. Assign OB35 as name of block.(→ OB35 → OK)



Name: OB35

Symbolischer Name:

Symbolkommentar:

Erstellsprache: AWL

Projektpfad:

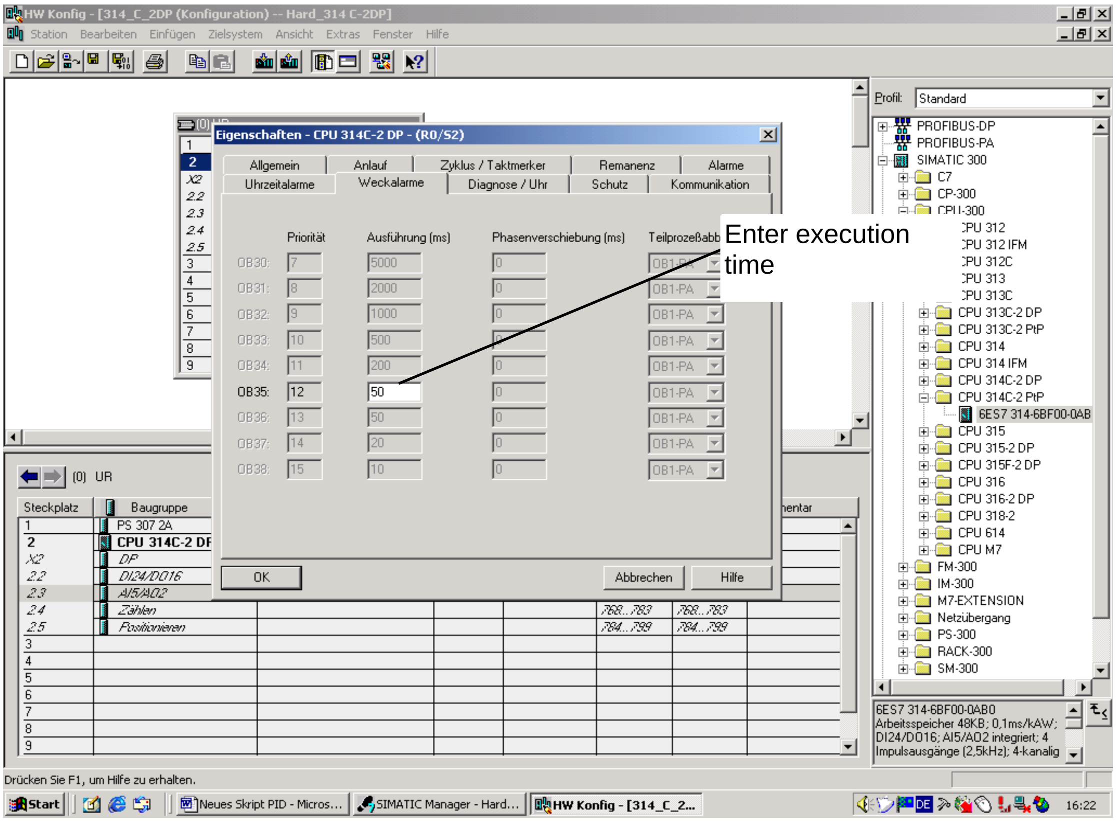
Speicherort des Projekts: C:\Copy\Ausbildungsunterlage_V3.0\PID_CONT

	Code	Schnittstelle
Erstellt am:	10.03.2003 22:45:36	
Zuletzt geändert am:	10.03.2003 22:45:36	10.03.2003 22:45:36

Kommentar:

Note: OB35 is a so-called **'Time interrupt OB'** and ensures a constant cycle for calling the PID controller block SFB41.
This is absolutely necessary so that the controller can be optimized by setting the controller parameters KP, TN and TV (for (S)FB41 Gain, TI and TD).
A cycle that under certain circumstances would fluctuate -as in the case of OB1- would cause the controlled system to fluctuate, and in the worst case, we would have a controlled variable that would be oscillating in an unstable way.

14. In the hardware configuration, at Properties of the CPU, a fixed cycle time can be set for executing OB35.
    However, this cycle time should not be selected too short. It has to be ensured that all blocks called from OB35 can be processed within this time, and if OB1 is used at the same time, that there is enough time for it also. (→ Execution)



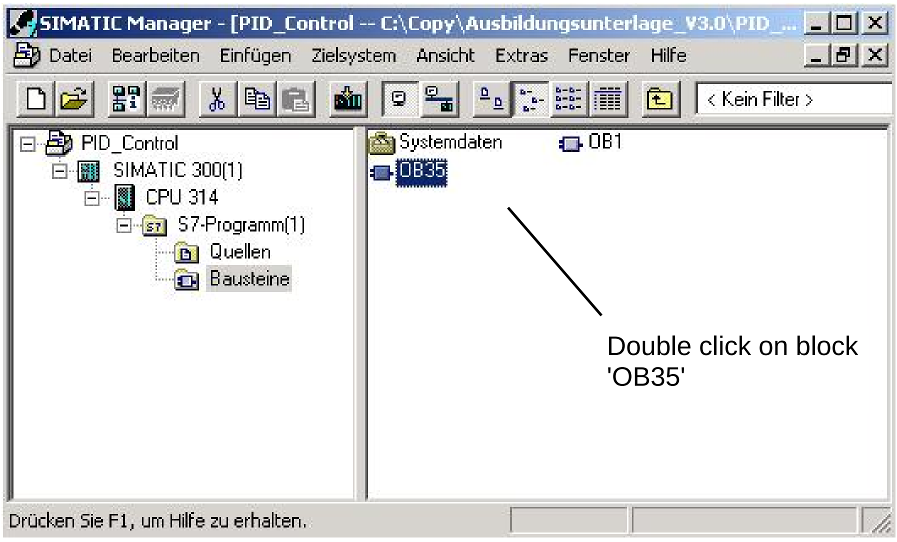
Eigenschaften - CPU 314C-2 DP - (R0/S2)

Weckalarme

	Priorität	Ausführung (ms)	Phasenverschiebung (ms)	Teilprozeßabb
OB30:	7	5000	0	OB1-PA
OB31:	8	2000	0	OB1-PA
OB32:	9	1000	0	OB1-PA
OB33:	10	500	0	OB1-PA
OB34:	11	200	0	OB1-PA
OB35:	12	50	0	OB1-PA
OB36:	13	50	0	OB1-PA
OB37:	14	20	0	OB1-PA
OB38:	15	10	0	OB1-PA

Enter execution time

15. Open **'OB35'** from SIMATIC Manager (→ OB35)



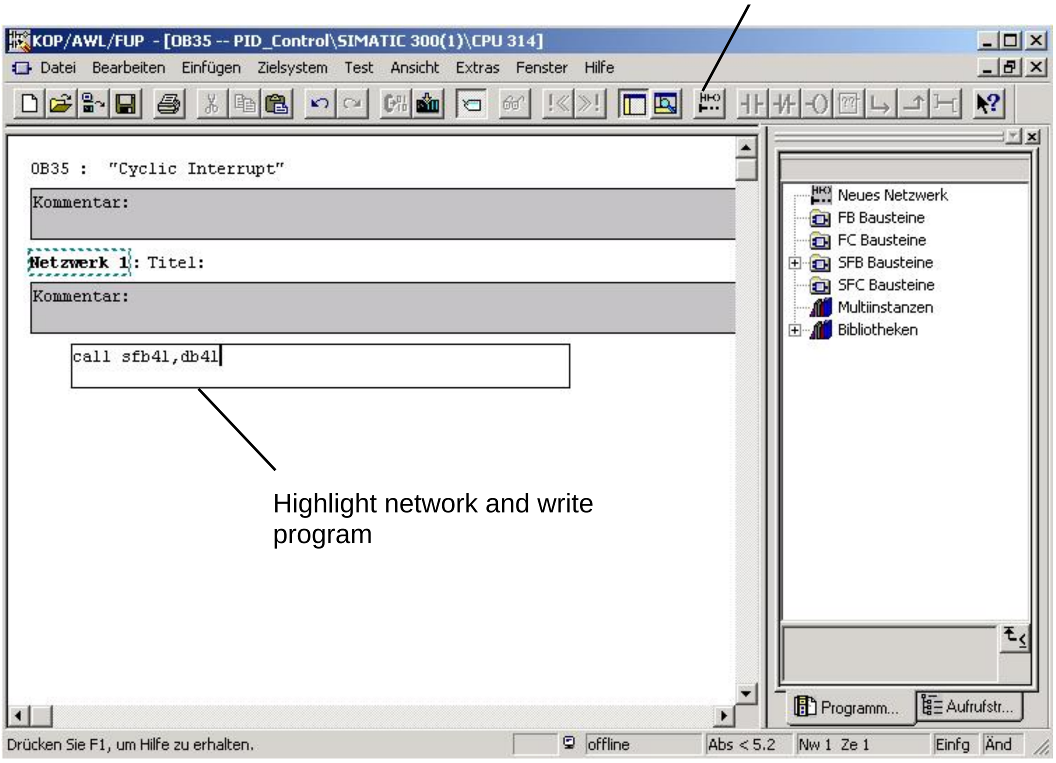
Double click on block 'OB35'

SIMATIC Manager - [PID_Control -- C:\Copy\Ausbildungsunterlage_V3.0\PID_...
Datei Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
< Kein Filter >
PID_Control
SIMATIC 300(1)
CPU 314
S7-Programm(1)
Quellen
Bausteine
Systemdaten
OB1
OB35
Drücken Sie F1, um Hilfe zu erhalten.

16. With ‘LAD, STL, and FBD – Program S7 Blocks’, you now have an editor that allows you to edit your STEP7 program accordingly. To this end, OB35 has already been opened with the first network.
    To generate your first operations, you have to highlight the first network. Now you can write your fist STEP7 program.
    In STEP 7, individual programs are usually subdivided into networks. You open a new network by clicking on the network symbol.

Note: Comments on program documentation are separated from the program commands by the character sequence“//“.

Open new network



KOP/AWL/FUP - [OB35 -- PID_Control\SIMATIC 300(1)\CPU 314]

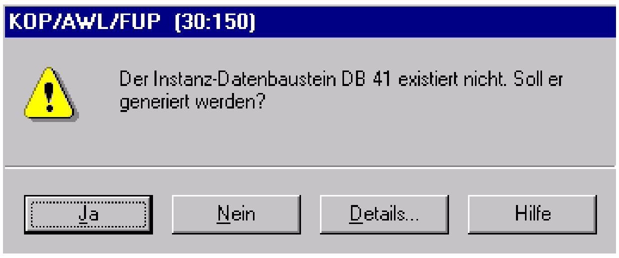
```
OB35 :  "Cyclic Interrupt"
Kommentar:

Netzwerk 1: Titel:
Kommentar:

    call sfb41,db41
```

Drücken Sie F1, um Hilfe zu erhalten.

Highlight network and write program

The network Call SFB41,DB41
calls the PID controller block SFB41 together with an instance DB.

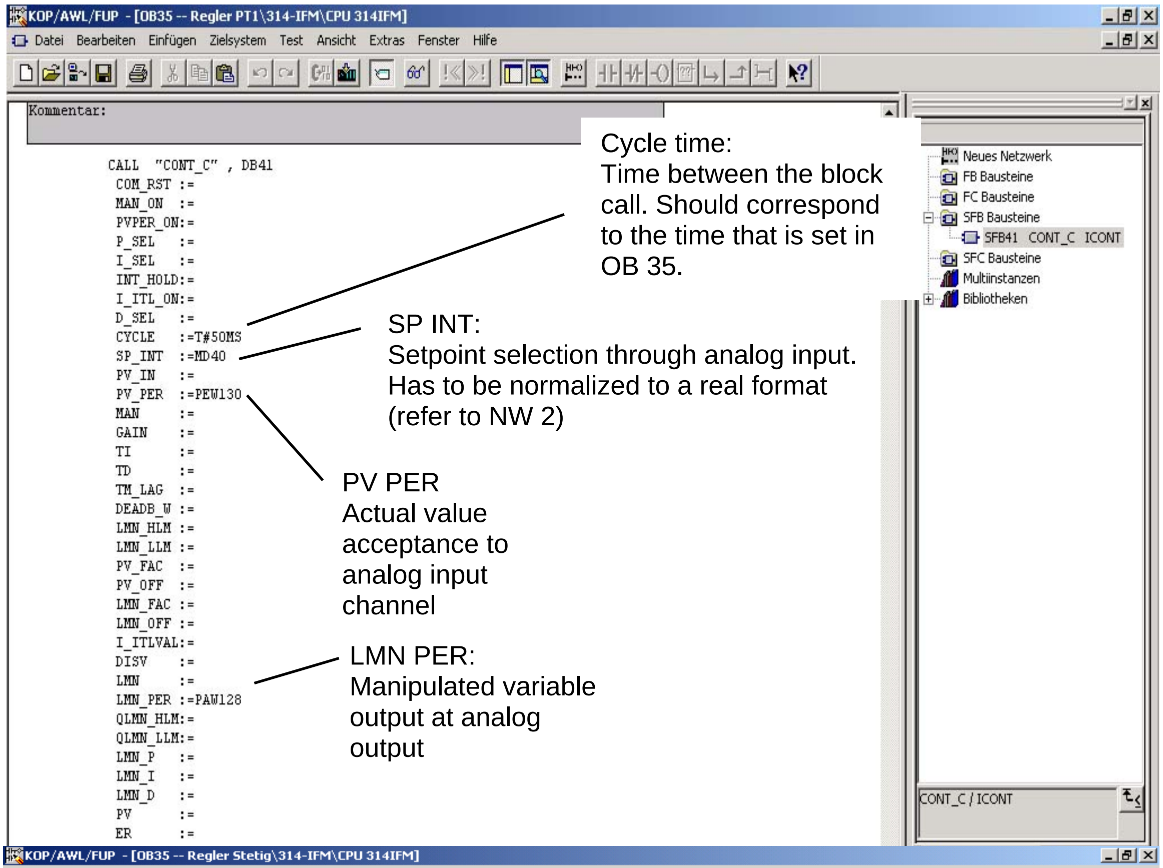
Generate instance DB (→ Yes)



KOP/AWL/FUP (30:150)

Der Instanz-Datenbaustein DB 41 existiert nicht. Soll er generiert werden?

17. The setpoint value, the actual value and the manipulated variable now have to be wired to process values as follows.



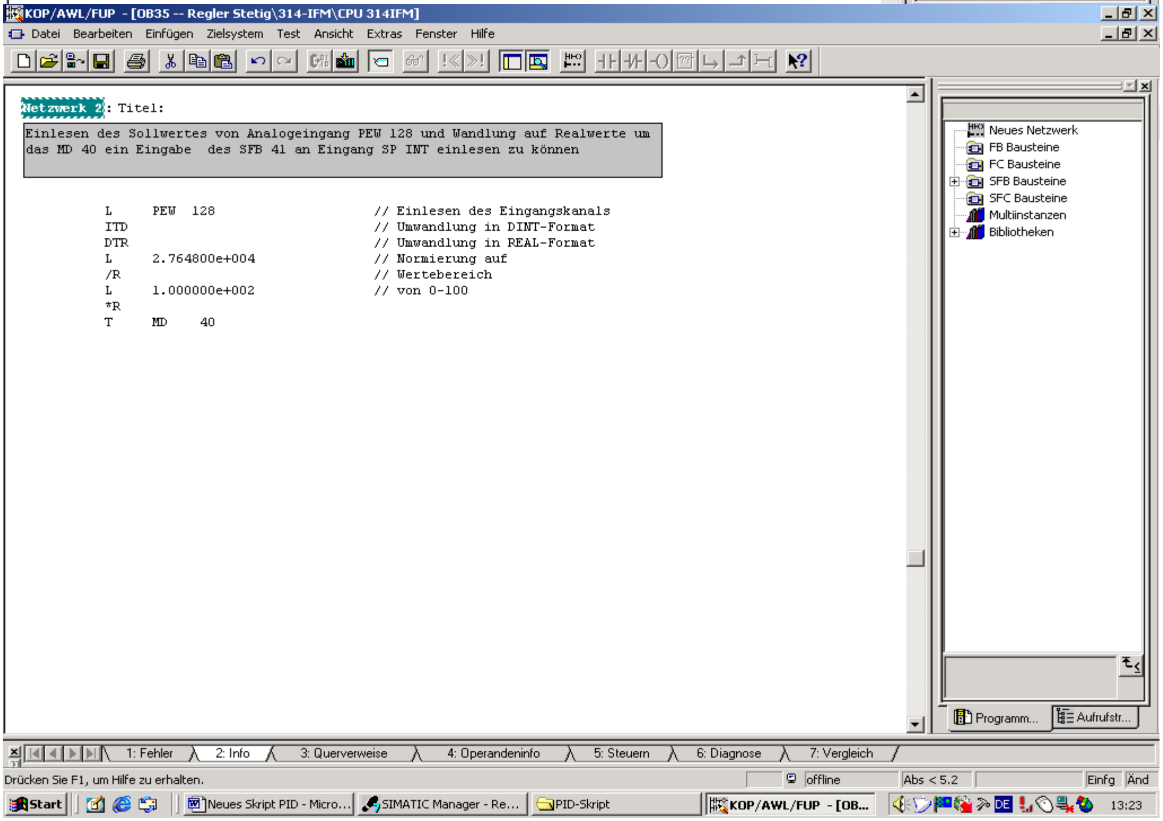
```
CALL  "CONT_C" , DB41
 COM_RST :=
 MAN_ON  :=
 PVPER_ON:=
 P_SEL   :=
 I_SEL   :=
 INT_HOLD:=
 I_ITL_ON:=
 D_SEL   :=
 CYCLE   :=T#50MS
 SP_INT  :=MD40
 PV_IN   :=
 PV_PER  :=PEW130
 MAN     :=
 GAIN    :=
 TI      :=
 TD      :=
 TM_LAG  :=
 DEADB_W :=
 LMN_HLM :=
 LMN_LLM :=
 PV_FAC  :=
 PV_OFF  :=
 LMN_FAC :=
 LMN_OFF :=
 I_ITLVAL:=
 DISV    :=
 LMN     :=
 LMN_PER :=PAW128
 QLMN_HLM:=
 QLMN_LLM:=
 LMN_P   :=
 LMN_I   :=
 LMN_D   :=
 PV      :=
 ER      :=
```

Cycle time:
Time between the block call. Should correspond to the time that is set in OB 35.

SP INT:
Setpoint selection through analog input. Has to be normalized to a real format (refer to NW 2)

PV PER
Actual value acceptance to analog input channel

LMN PER:
Manipulated variable output at analog output



Netzwerk 2: Titel:

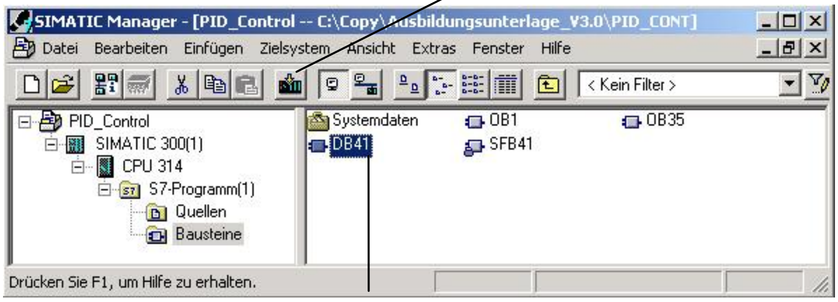
Einlesen des Sollwertes von Analogeingang PEW 128 und Wandlung auf Realwerte um das MD 40 ein Eingabe des SFB 41 an Eingang SP INT einlesen zu können

```
L     PEW  128                  // Einlesen des Eingangskanals
ITD                             // Umwandlung in DINT-Format
DTR                             // Umwandlung in REAL-Format
L     2.764800e+004             // Normierung auf
/R                              // Wertebereich
L     1.000000e+002             // von 0-100
*R
T     MD    40
```

18. Save and load OB35 (CPU’s key switch is on Stop!)

19. In ‘SIMATIC Manager’, highlight block DB41 and load to the PLC. (CPU’s key switch is on Stop!)

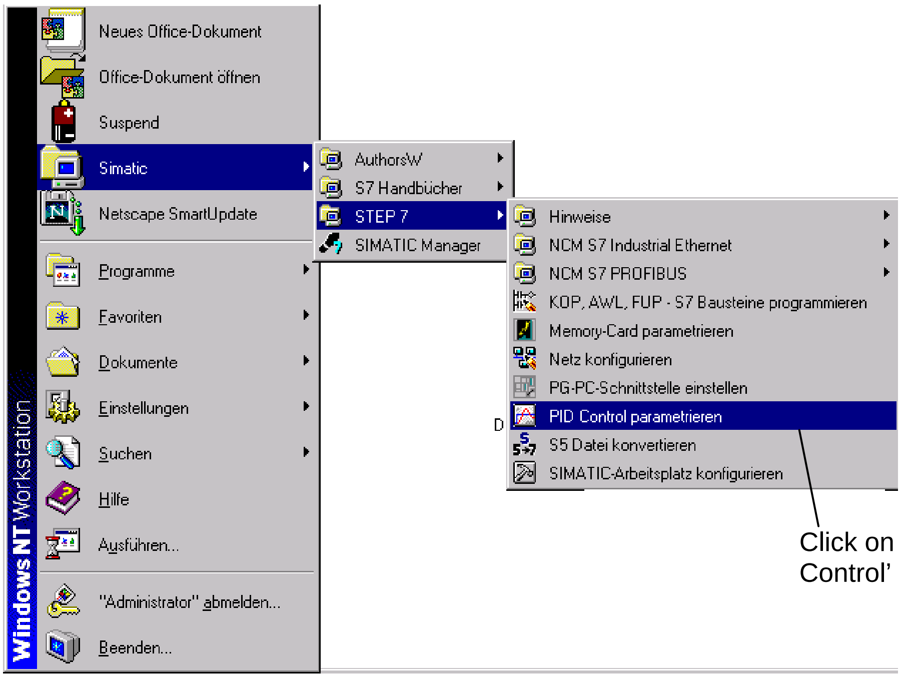
Click on symbol ‘Load to PLC’



SIMATIC Manager - [PID_Control -- C:\Copy\Ausbildungsunterlage_V3.0\PID_CONT]
Datei Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
< Kein Filter >
PID_Control
SIMATIC 300(1)
CPU 314
S7-Programm(1)
Quellen
Bausteine
Systemdaten
OB1
OB35
DB41
SFB41
Drücken Sie F1, um Hilfe zu erhalten.

Click on DB41

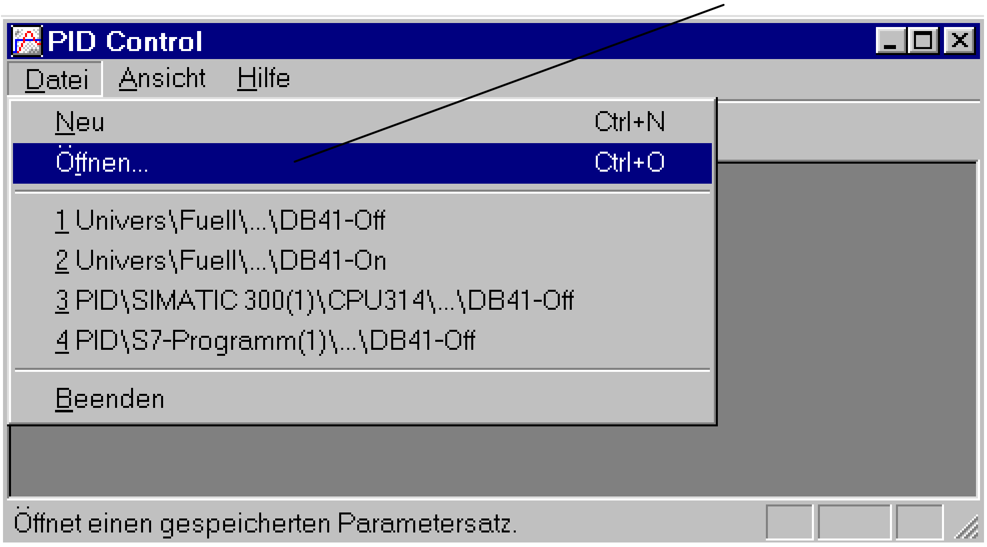
20. Call the tool **Assign parameters to the PID control** (→ Start → Simatic → STEP 7 → Parameterize PID Control)



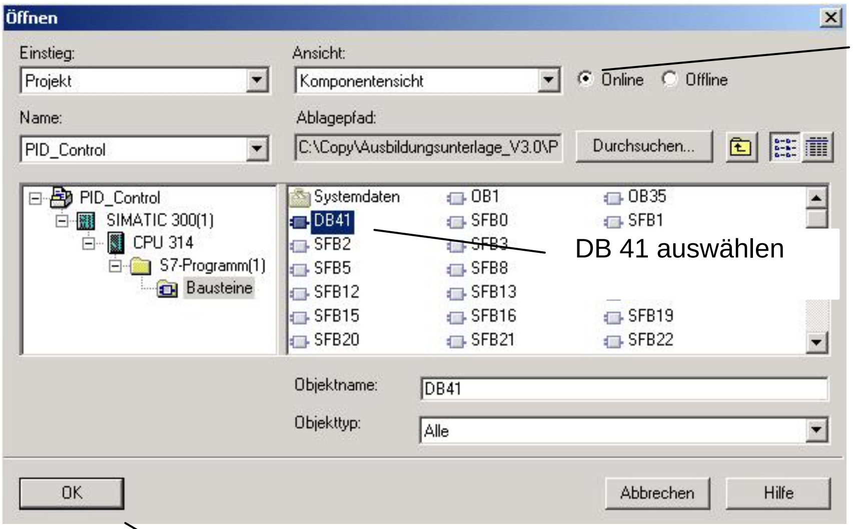
Click on 'Parameterize PID Control'

21. Open data block (→ File → Open → Online
→ Select data block; for example, DB41 → OK).

Click on ‘Open’


PID Control
Datei
Ansicht
Hilfe
Neu Ctrl+N
Öffnen... Ctrl+O
1 Univers\Fuell\...\DB41-Off
2 Univers\Fuell\...\DB41-On
3 PID\SIMATIC 300(1)\CPU314\...\DB41-Off
4 PID\S7-Programm(1)\...\DB41-Off
Beenden

Öffnet einen gespeicherten Parametersatz.



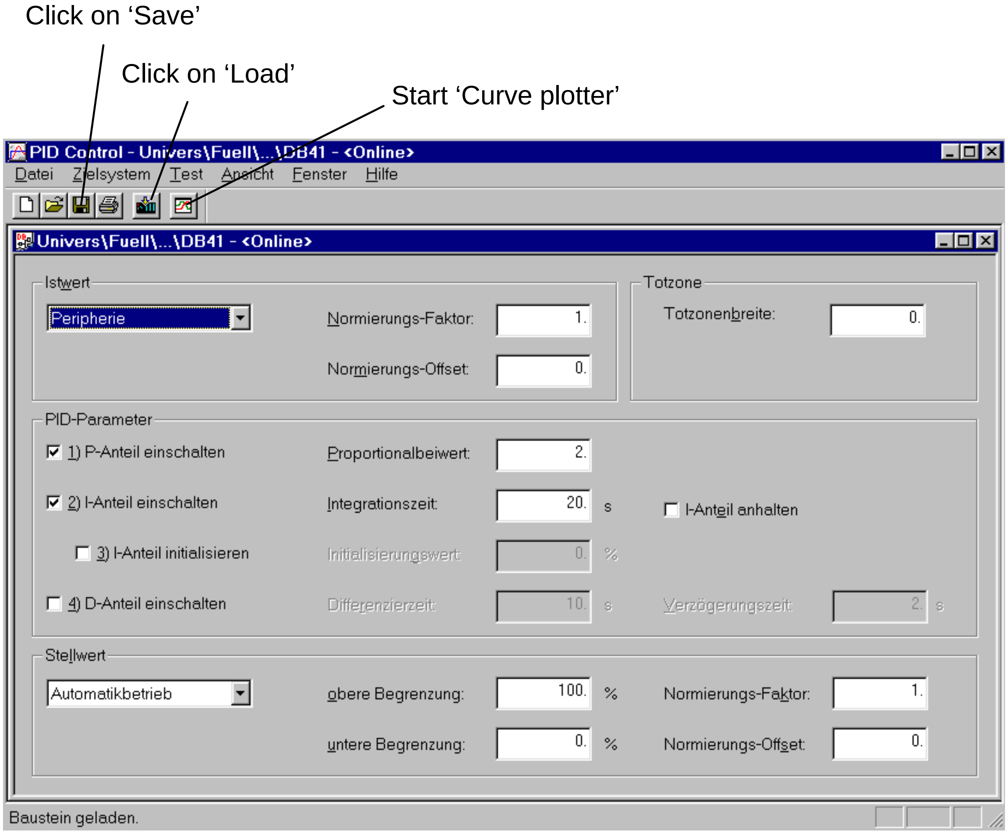
Einstieg: Projekt
Ansicht: Komponentensicht ● Online ○ Offline
Name: PID_Control
Ablagepfad: C:\Copy\Ausbildungsunterlage_V3.0\P
PID_Control
SIMATIC 300(1)
CPU 314
S7-Programm(1)
Bausteine
Objektname: DB41
Objekttyp: Alle

Switch block to the online mode

DB 41 auswählen

Click on ‘OK’

22. The PID controller can now be parameterized with the tool **Parameterize PID Control**. Then, the DB is saved (→ Save) and loaded to the PLC (→ Load).
Now, a curve plotter can be started in order to monitor the performance of the controlled system.



Click on ‘Save’

Click on ‘Load’

Start ‘Curve plotter’

PID Control - Univers\Fuell\...\DB41 - <Online>

Datei Zielsystem Test Ansicht Fenster Hilfe

Univers\Fuell\...\DB41 - <Online>

Istwert

Peripherie

Normierungs-Faktor: 1.

Normierungs-Offset: 0.

Totzone

Totzonenbreite: 0.

PID-Parameter

☑ 1) P-Anteil einschalten — Proportionalbeiwert: 2.

☑ 2) I-Anteil einschalten — Integrationszeit: 20. s — □ I-Anteil anhalten

□ 3) I-Anteil initialisieren — Initialisierungswert: 0. %

□ 4) D-Anteil einschalten — Differenzierzeit: 10. s — Verzögerungszeit: 2. s

Stellwert

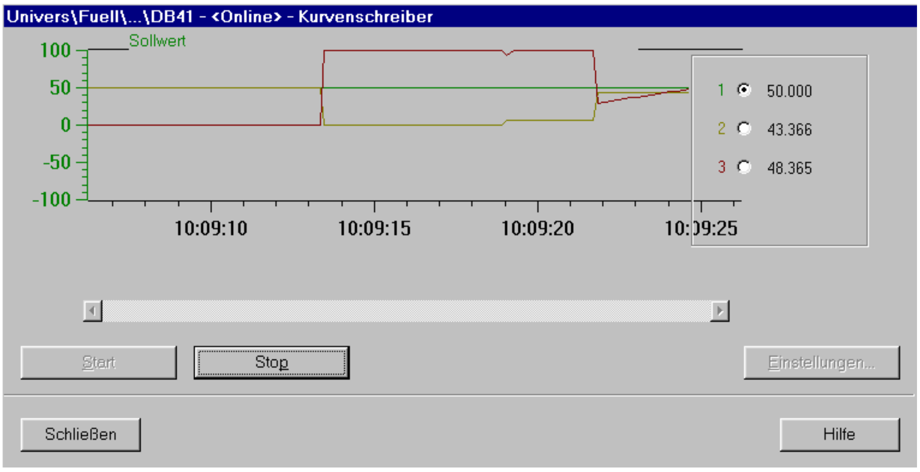
Automatikbetrieb

obere Begrenzung: 100. % — Normierungs-Faktor: 1.

untere Begrenzung: 0. % — Normierungs-Offset: 0.

Baustein geladen.

23. With the curve plotter, the curves for setpoint, actual value and manipulated variable can be recorded.



Univers\Fuell\...\DB41 - <Online> - Kurvenschreiber

1 ● 50.000

2 ○ 43.366

3 ○ 48.365

24. The program is started by setting the key switch to RUN.

5. SETTING CONTROLLED SYSTEMS

5.1 General

Below, setting controlled systems is discussed, using a PT2 system as an example.

T_u-T_g Approximation

The basis for the methods according to Ziegler-Nichols and according to Chien, Hrones and Reswick is the T_u-T_g approximation. With it, the parameters following parameters transfer coefficient of the system K_S, delay T_u und transition time T_g can be determined from the system step response.
The rules for controller adjustment that are described below were found experimentally, by using analog computer simulations.
P-T_N systems can be described with sufficient accuracy with a so-called T_u-T_g approximation; that means, through approximation by means of a P-T_1-T_L system.
Starting point is the system step response with the input step height K. The necessary parameters: transfer coefficient of the system K_S, delay T_u and transition time T_g are ascertained as shown in the figure below.
This requires measuring the transition function up to the stationary upper range value (K*Ks), so that the transfer coefficient for system $K_{S,}$ required for the calculation, can be determined.
The essential advantage of these methods is that the approximation can also be used if the system can not be described analytically.

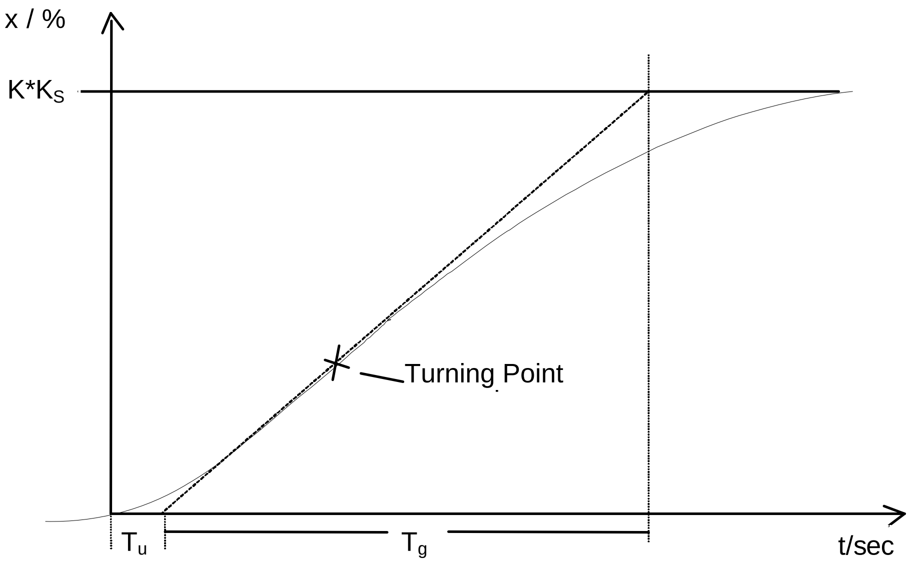


Figure: T_u-T_g Approximation

5.2 Setting the PI-Controller according to Ziegler-Nichols

By experimenting with P-T_1-T_L systems, Ziegler and Nichols have found the following optimum controller settings for fixed setpoint control:

$$K_{PR} = 0.9 \frac{T_g}{K_S T_u}$$

$$T_N = 3.33\ T_u$$

In general, we get disturbance characteristics with these setting values that are quite good. [7]

5.3 Setting the PID Controller according to Chien, Hrones and Reswick

For this method, the response to setpoint characteristics as well as disturbance characteristics was examined, in order to get the most favorable controller parameters. Different values resulted for both cases.

The following settings were the result:

- For disturbance characteristics:

Apriodical transient reaction with the shortest period	20% overshoot Minimum period of oscillation
$K_{PR} = 0.6 \frac{T_g}{K_S T_u}$	$K_{PR} = 0.7 \frac{T_g}{K_S T_u}$
$T_N = 4\ T_u$	$T_N = 2.3\ T_u$

- For setpoint characteristic:

Apriodical transient reaction
with the shortest period

$$K_{PR} = 0.35 \frac{T_g}{K_S T_u}$$

$$T_N = 1.2 \; T_g$$

20% overshoot
Minimum period of oscillation

$$K_{PR} = 0.6 \frac{T_g}{K_S T_u}$$

$$T_N = T_g$$

5.4 Exercise Example

To accommodate the system step response, a few modifications have to be made in OB 35 and DB41. The following steps have to be performed for this:

Save your old project under a new name, and change the wiring of (S)FB 41 as follows:

1. With STEP7, specify the manipulated value directly.

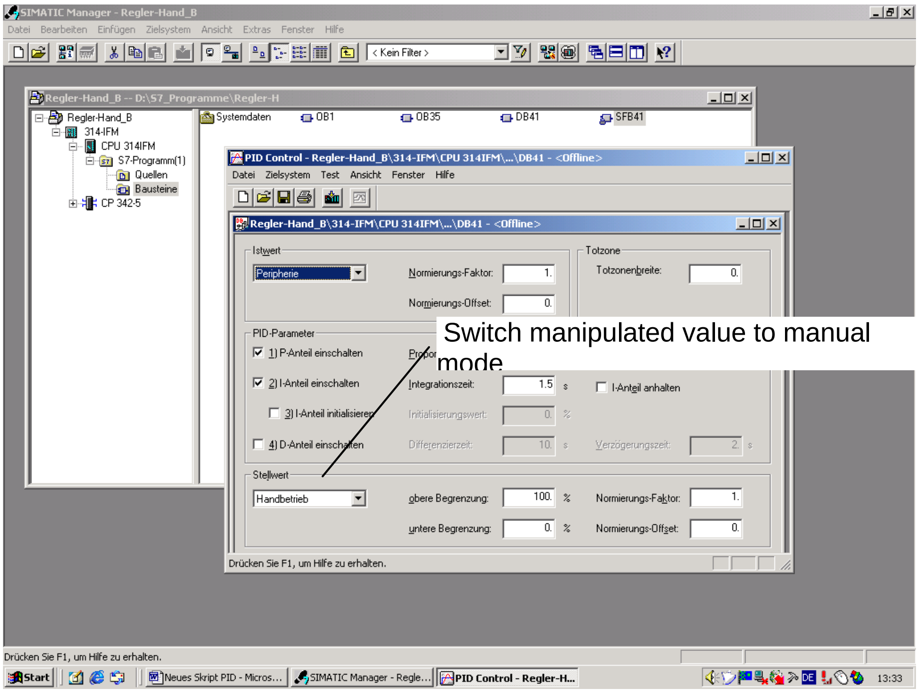
The manipulated value is to be specified in the network below in a way that with a switch S1 (I 124.0), a selection can be made between two manipulated values.

```
              L      0.000000e+000     //Manipulated value 0% as 32 bit floating point number
              UN     I 124.0           //Negation of S1 (I 124.0)
              SPB    M001              //Jump if RLO = 1 to label M001
              L      1.000000e+002     //Manip.value 100% as 32 bit floating pt. nbr.
M001:         T      MD 20             //Transfer the value to flag double word MD 20
```

Now, for the switch position S1(I 124.0) ON, the manipulated variable y = 100%, and for OFF, the manipulated variable y = 0%. Consequently, a step of the manipulated value from 0 to 100% can be brought about with Switch S1. (For systems that tend to overshoot, the high manipulated value should amount to 90% or less.).

The external analog values and the manipulated value are assigned in OB1 as follows:

```
      MAN         :=     MD 20        //Specify the manipulated value as manual value
      PV_PER      :=     PEW 130      //Actual value x
      LMN_PER     :=     PAW 128      //Manipulated variable  y
```


SIMATIC Manager - Regler-Hand_B
Datei Bearbeiten Einfügen Zielsystem Ansicht Extras Fenster Hilfe
< Kein Filter >
Regler-Hand_B -- D:\S7_Programme\Regler-H
Regler-Hand_B
314-IFM
CPU 314IFM
S7-Programm(1)
Quellen
Bausteine
CP 342-5
Systemdaten
OB1
OB35
DB41
SFB41
PID Control - Regler-Hand_B\314-IFM\CPU 314IFM\...\DB41 - <Offline>
Datei Zielsystem Test Ansicht Fenster Hilfe
Regler-Hand_B\314-IFM\CPU 314IFM\...\DB41 - <Offline>

Istwert: Peripherie; Normierungs-Faktor: 1.; Normierungs-Offset: 0.

Totzone: Totzonenbreite: 0.

PID-Parameter:
☑ 1) P-Anteil einschalten
☑ 2) I-Anteil einschalten — Integrationszeit: 1.5 s — ☐ I-Anteil anhalten
☐ 3) I-Anteil initialisieren — Initialisierungswert: 0. %
☐ 4) D-Anteil einschalten — Differenzierzeit: 10. s — Verzögerungszeit: 2. s

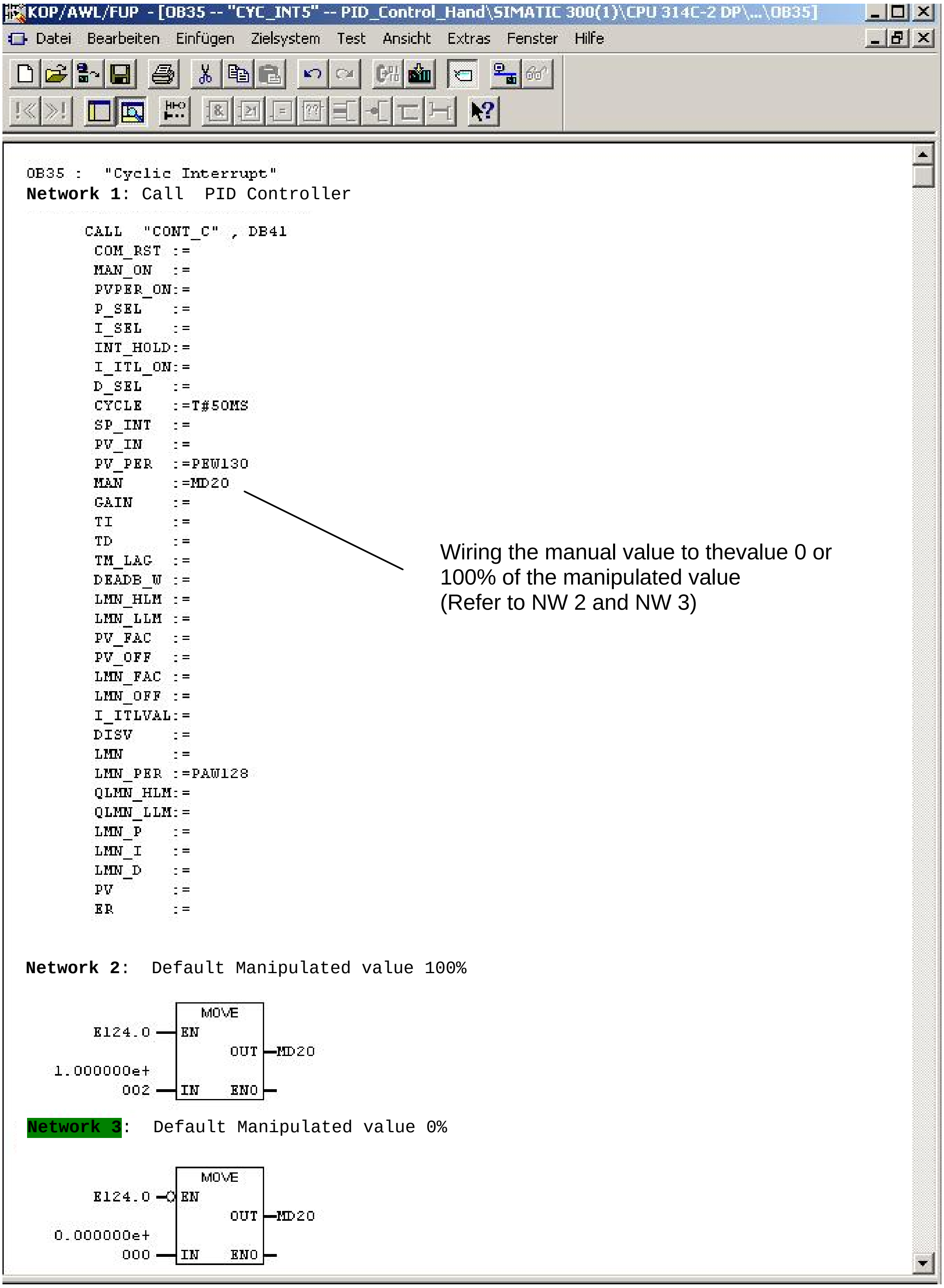
Stellwert: Handbetrieb; obere Begrenzung: 100. %; untere Begrenzung: 0. %; Normierungs-Faktor: 1.; Normierungs-Offset: 0.

Drücken Sie F1, um Hilfe zu erhalten.

Switch manipulated value to manual mode

Drücken Sie F1, um Hilfe zu erhalten.
Start
Neues Skript PID - Micros...
SIMATIC Manager - Regle...
PID Control - Regler-H...
13:33

Solution of the PLC program:


KOP/AWL/FUP - [OB35 -- "CYC_INT5" -- PID_Control_Hand\SIMATIC 300(1)\CPU 314C-2 DP\...\OB35]
Datei Bearbeiten Einfügen Zielsystem Test Ansicht Extras Fenster Hilfe

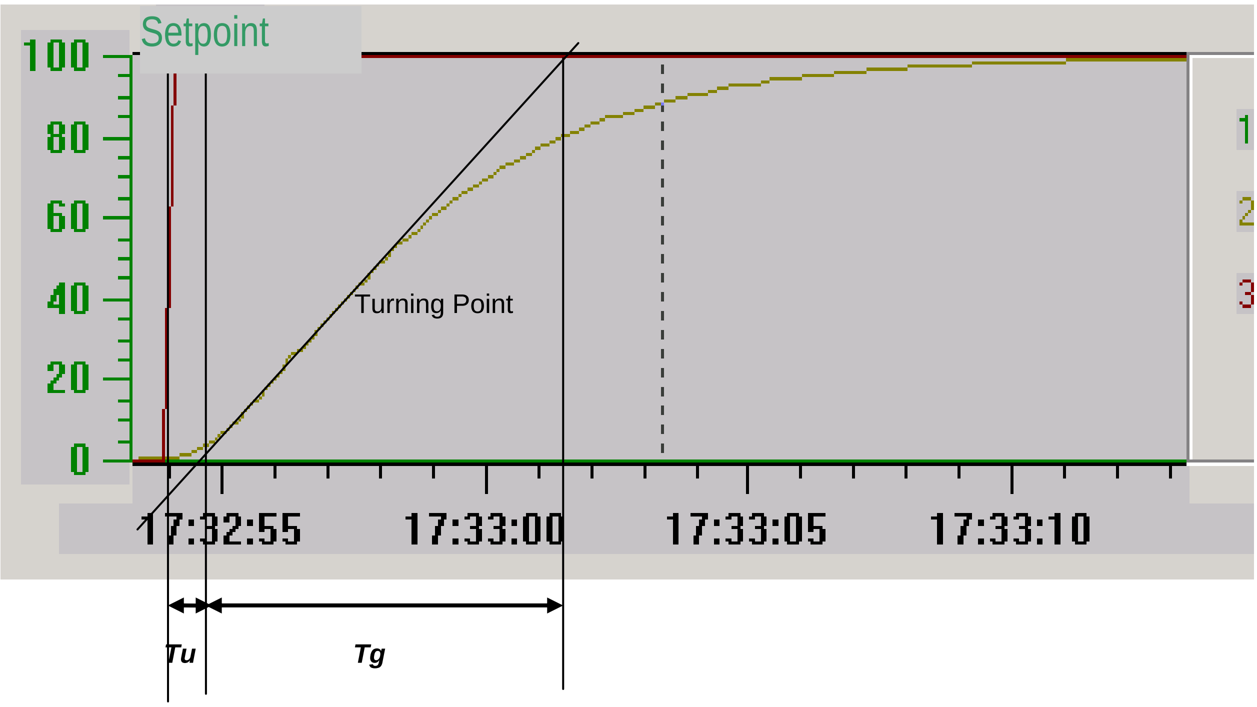
```
OB35 :  "Cyclic Interrupt"
Network 1: Call  PID Controller

      CALL  "CONT_C" , DB41
       COM_RST  :=
       MAN_ON   :=
       PVPER_ON:=
       P_SEL    :=
       I_SEL    :=
       INT_HOLD:=
       I_ITL_ON:=
       D_SEL    :=
       CYCLE    :=T#50MS
       SP_INT   :=
       PV_IN    :=
       PV_PER   :=PEW130
       MAN      :=MD20
       GAIN     :=
       TI       :=
       TD       :=
       TM_LAG   :=
       DEADB_W  :=
       LMN_HLM  :=
       LMN_LLM  :=
       PV_FAC   :=
       PV_OFF   :=
       LMN_FAC  :=
       LMN_OFF  :=
       I_ITLVAL:=
       DISV     :=
       LMN      :=
       LMN_PER  :=PAW128
       QLMN_HLM:=
       QLMN_LLM:=
       LMN_P    :=
       LMN_I    :=
       LMN_D    :=
       PV       :=
       ER       :=
```

Wiring the manual value to thevalue 0 or 100% of the manipulated value
(Refer to NW 2 and NW 3)

```
Network 2:  Default Manipulated value 100%

                 MOVE
     E124.0 ---|EN        |
               |      OUT |--MD20
 1.000000e+    |          |
        002 ---|IN    ENO |--

Network 3:  Default Manipulated value 0%

                 MOVE
     E124.0 --o|EN        |
               |      OUT |--MD20
 0.000000e+    |          |
        000 ---|IN    ENO |--
```

Then, the system step response is recorded with the curve plotter from 0 to 100%.

For systems that tend to overshoot, 90% should be assigned as step value.



System step response for T_u-T_g approximation

After the inflectional tangent is drawn in the figure, the following values can be read:

T_u = 0.7s

T_g = 7s

1.0 * K_S = 1.0

The result is K_S = 1.0 and the ratio T_g/K_S = 7s.

Setting the PI controller according to Ziegler-Nichols

The following controller parameters result with the values T_u-T_g approximation, and the rules for controller adjustment according to Ziegler-Nichols:

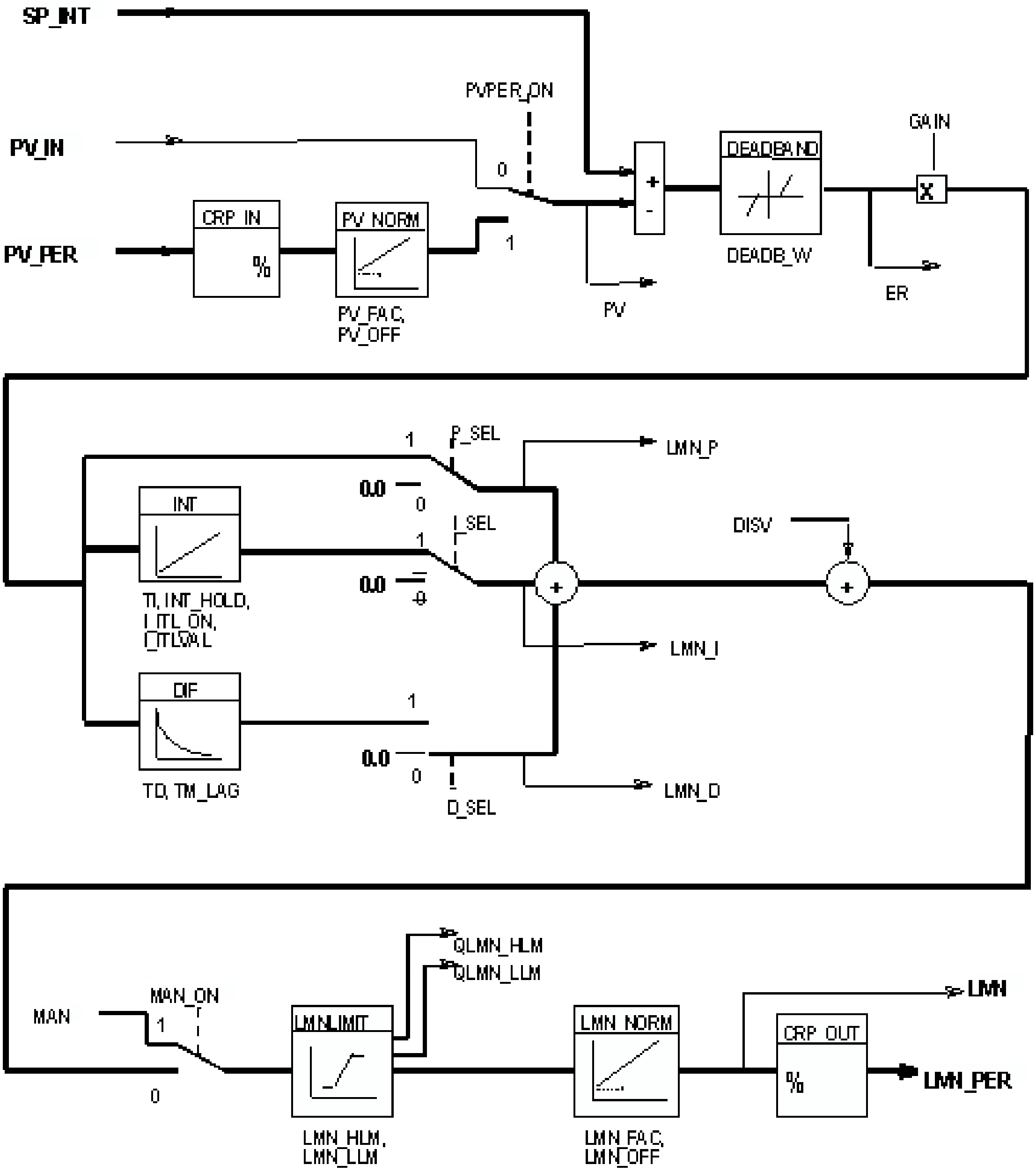
K_{PR} = 9

T_N = 2.3s

These controller parameters are transferred to DB41.

6. APPENDIX

Diagram of the controller block:



Input Parameters

Parameter	Data Type	Value Range	Default	Description
COM_RST	BOOL		FALSE	COMPLETE RESTART. The block has a complete restart routine that is processed if the input is set to "Complete restart".
MAN_ON	BOOL		TRUE	MANUAL VALUE ON / Switch on manual operation. If the input "switch on manual operation" is set, the control loop has been interrupted. A manipulated value is entered as manual value.
PVPER_ON	BOOL		FALSE	PROCESS VARIABLE PERIPHERY ON / Actual value Switch on the periphery. If the periphery is to read in the actual value, input PV_PER has to be wired to the periphery, and the input "Switch on actual value periphery" has to be set.
P_SEL	BOOL		TRUE	PROPORTIONAL ACTION ON / Switch on P-component. In the PID algorithm, the PID components can be switched on/off individually. The P-component is switched on if the input "Switch on P-component" is set.
I_SEL	BOOL		TRUE	INTEGRAL ACTION ON / Switch on I-component. In the PID algorithm, the PID components can be switched on/off individually. The I-component is switched on if the input "Switch on I- component" is set.
INT_HOLD	BOOL		FALSE	INTEGRAL ACTION HOLD / Freeze I-component. The output of the integrator can be frozen. To this end, the input "Freeze I-component“ is set.
I_ITL_ON	BOOL		FALSE	INITIALIZATION OF THE INTEGRAL ACTION / Set I-component. The output of the integrator can be set to the input I_ITL_VAL. To this end, the input "Set I-component“ has to be set.
D_SEL	BOOL		FALSE	DERIVATIVE ACTION ON / Switch on D-component. In the PID algorithm, the PID components can be switched on/off individually. The D-component is switched on if the input "Switch on D-component" is set.

Parameter	Data Type	Value Range	Default	Description
CYCLE	TIME	>= 1 ms	T#1s	SAMPLE TIME. The time between block calls has to be constant. The input "Sample time" indicates the time between block calls.
SP_INT	REAL	-100.0...+100.0%	0.0	INTERNAL SETPOINT. The input "Internal setpoint" is used to specify the setpoint.
PV_IN	REAL	-100.0...+100.0%	0.0	PROCESS VARIABLE IN / Actual value input. At the input "Actual value input", a startup value can be parameterized, or an external actual value can be wired in the floating point format.
PV_PER	WORD		W#16#0000	PROCESS VARIABLE PERIPHERy / Actual value Periphery. The actual value in the periphery format is wired to the controller at the input "Actual value Periphery ".
MAN	REAL	-100.0...+100.0%	0.0	MANUAL VALUE. The input "Manual value" is used to specify a manual value by means of the operator interface function.
GAIN	REAL		2.0	PROPORTIONAL GAIN /Proportional coefficient. The input "Proportional coefficient" indicates controller gain.
TI	TIME	>= CYCLE	T#20s	RESET TIME / Integration time. The input "Integration time" determines the time response of the integrator.
TD	TIME	>= CYCLE	T#10s	DERIVATIVE TIME. The input "Derivative time" determines the time response of the differentiator.
TM_LAG	TIME	>=CYCLE/2	T#2s	TIME LAG OF THE DERIVATE ACTION / Delay of the D-component. The algorithm of the D-component contains a delay that can be parameterized at the input "Time lag of the derivative action".
DEADB_W	REAL	>=0.0 %	0.0	DEAD BAND WIDTH. The system deviation is taken via a dead band. The "Dead band width" determines the size of the dead band.

Parameter	Data Type	Value Range	Default	Description
LMN_HLM	REAL	LMN_LLM... +100.0 % or phys. variable 2	100.0	MANIPULATED VALUE HIGH LIMIT. The manipulated value is always limited to a high and a low limit. "Manipulated value high limit" indicates the high limit.
LMN_LLM	REAL	-100.0... LMN_HLM % phys. variable 2	0.0	MANIPULATED VALUE LOW LIMIT. The manipulated value is always limited to a high and a low limit. "Manipulated value low limit" indicates the low limit.
PV_FAC	REAL		1.0	PROCESS VARIABLE FACTOR / actual value factor. The input "Actual value factor" is multiplied with the actual value. The input is used for adjusting the actual value range.
PV_OFF	REAL		0.0	PROCESS VARIABLE OFFSET / Actual value offset. The input "Actual value offset" is added to the actual value. The input is used for adjusting the actual value range.
LMN_FAC	REAL		1.0	MANIPULATED VALUE FACTOR The input "Manipulated value factor" is multiplied with the manipulated value. The input is used for adjusting the manipulated value range.
LMN_OFF	REAL		0.0	MANIPULATED VALUE OFFSET. The input "Manipulated value offset" is added to the manipulated value. The input is used for adjusting the manipulated value range.
I_ITLVAL	REAL	-100.0...+100.0% or phys. variable 2	0.0	INITIALIZATION VALUE OF THE INTEGRAL ACTION / Initialization value for the I-component. The output of the integrator can be set at the input I_ITL_ON. The initialization value is located at the input "Initialization value for I-component". .
DISV	REAL	-100.0...+100.0% or phys. variable 2	0.0	DISTURBANCE VARIABLE. Feedforward control is wired at the input "Disturbance variable".

Output Parameters:

Parameter	Data Type	Value Range	Default	Description
LMN	REAL	0.0		MANIPULATED VALUE. At the output "Manipulated value", the effectively active manipulated value is read out in the floating point format.
LMN_PER	WORD	W#16#0000		MANIPULATED VALUE PERIPHERY. The manipulated value in the periphery format is wired to the controller at the output of "Manipulated value periphery“.
QLMN_HLM	BOOL	FALSE		HIGH LIMIT OF MANIPULATED VALUE REACHED. The manipulated value is always limited to a high and low limit. The output "High limit of manipulated value reached" signals that the high limit has been exceeded.
QLMN_LLM	BOOL	FALSE		LOW LIMIT OF MANIPULATED VALUE REACHED. The manipulated value is always limited to a high and low limit. The output "Low limit of manipulated value reached" signals that the low limit is underrange.
LMN_P	REAL	0.0		PROPORTIONALITY COMPONENT. The output "P-component" contains the proportional component of the manipulated variable.
LMN_I	REAL	0.0		INTEGRAL COMPONENT. The output "I-component“ contains the integral component of the manipulated variable.
LMN_D	REAL	0.0		DERIVATIVE COMPONENT. The output "D-component" contains the derivative component of the manipulated variable.
PV	REAL	0.0		PROCESS VARIABLE / actual value. At the output "Actual value", the effectively active actual value is read out.
ER	REAL	0.0		ERROR SIGNAL / System deviation. At the output "System deviation", the effectively active system deviation is read out.