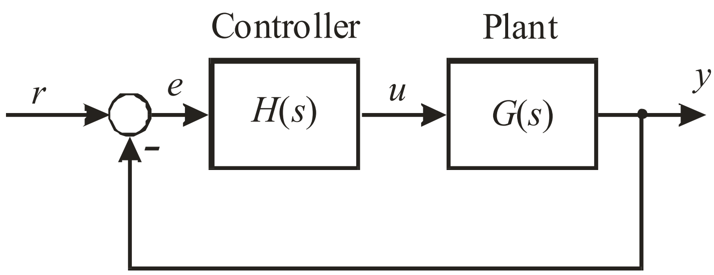
5

Design of linear control loops with RESY

Overview

RESY allows the analysis, design and simulation of linear standard control loops with the following structure:

Closed loop structure



Control loop structure

Controller and plant can be built-up stepwise from linear standard elements. The table below contains all available elements with their corresponding transfer function and some remarks.

Type	Transfer function $H_i(s)$ resp. $G_i(s)$	Remarks
P	K_P	
P-T1	$\frac{K_P}{1+T_1 s}$	plant only
P-T2	$\frac{K_P}{(1+T_1 s)(1+T_2 s)}$	plant only
P-T3	$\frac{K_P}{(1+T_1 s)(1+T_2 s)(1+T_3 s)}$	plant only
P-T2S	$\frac{K_P}{\left(\frac{s}{\omega_0}\right)^2+\frac{2D}{\omega_0}s+1}$	plant only

I	$\dfrac{K_I}{s}$	
I-T1	$\dfrac{K_I}{s(1+T_1 s)}$	plant only
P-Tt	$K_P \ e^{-T_t s}$	plant only
D-T1	$\dfrac{T_D s}{1+T_1 s}$	plant only
LEAD/LAG	$K_P \dfrac{1+T_1 s}{1+T_2 s}$	
TransFct	$\dfrac{b_m s^m + b_{m-1} s^{m-1} + \ldots + b_1 s + b_0}{s^n + a_{n-1} s^{n-1} + \ldots + a_1 s + a_0} e^{-T_t s}$	
PDT1	$K_P \left(1 + \dfrac{T_V s}{1+T_1 s}\right)$	controller only
PI	$K_P \left(1 + \dfrac{1}{T_N s}\right)$	controller only
PIDT1	$K_P \left(1 + \dfrac{1}{T_N s} + \dfrac{T_V s}{1+T_1 s}\right)$	controller only

Based on this information RESY determines

- the total transfer function $H(s)$ of the controller,
- the total transfer function $G(s)$ of the plant,
- the transfer function $L(s) = G(s)H(s)$ of the open-loop system,

- the transfer function $T(s) = L(s) / (1 + L(s))$ of the closed-loop system,
- the corresponding frequency responses $G(\mathrm{j}\omega)$, $H(\mathrm{j}\omega)$, $L(\mathrm{j}\omega)$, $T(\mathrm{j}\omega)$

and within the time domain for a step reference function $r(t)$ the course of

- the error variable $e(t)$,
- the manipulated variable (controller output) $u(t)$,
- the controlled variable (plant output) $y_\mathrm{T}(t)$

as well as the step response $y_\mathrm{G}(t)$ of the plant itself.

For time domain as well as for frequency domain characteristic values can be determined to get an idea of the dynamic behaviour of the system. For time domain these are

Characteristic values

- The overshoot M_p of the step response of the closed-loop system.
  This value is determined from the maximum of the controlled variable during the transient.
- The settling time T_a related to a tolerance band with a width of 10% of the stationary value of the controlled variable. This value is a property characterizing the velocity of the transient step response.
- The steady-state error signal $e(t \to \infty)$.
- The maximum of the manipulated variable (control output) u_max.
  This value is determined as the maximum absolute value $u(t)$ during the transient step response.

The open loop is characterized by the following frequency domain properties:

- The gain crossover frequeny ω_c; that is the frequency where the gain crosses the 0 db-axis.
- The phase margin Φ_r, which is defined as the difference between the phase and the -180° axis at the gain crossover frequency.

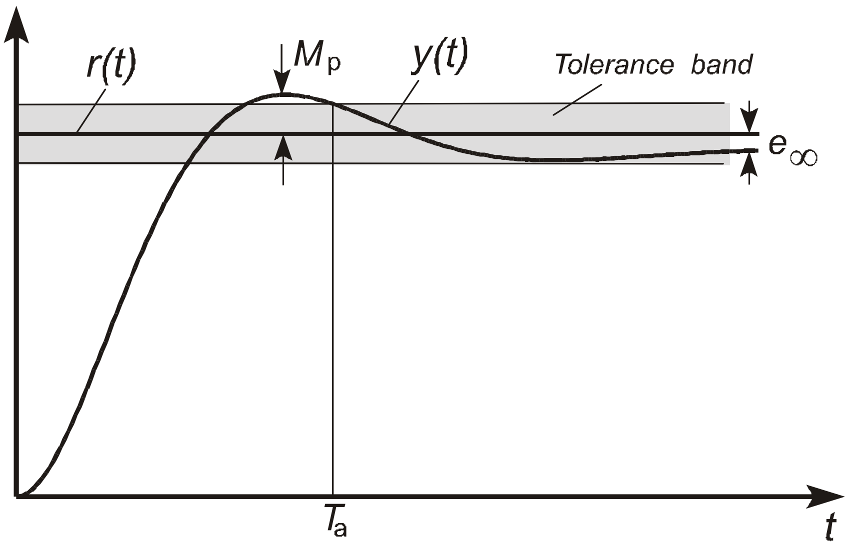
- The amplitude margin A_r, which is defined as the negative gain of the open loop at that frequency where the phase crosses the -180° axis.

For the closed loop frequency domain the following properties are determined:

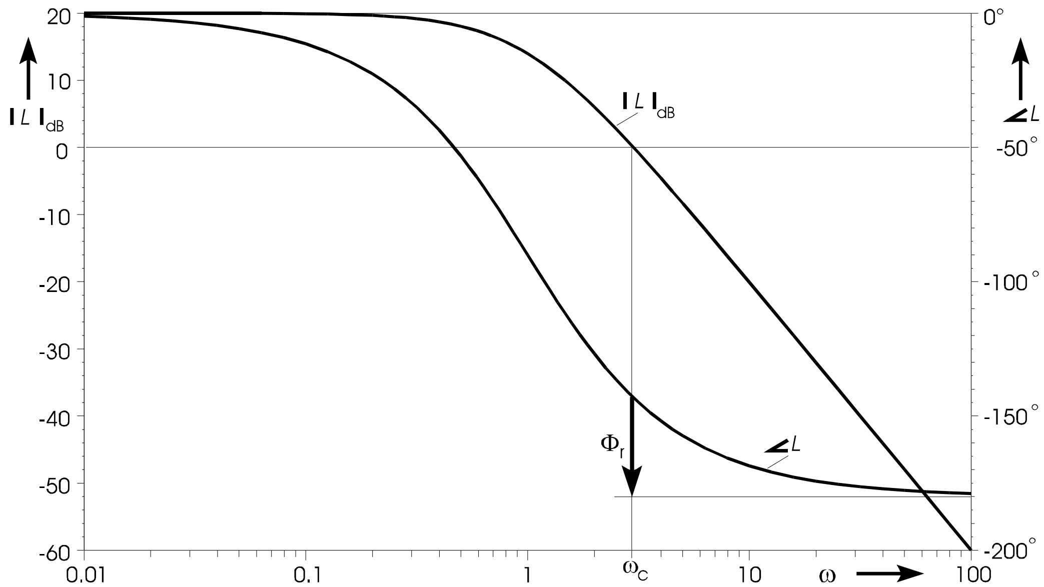
- The bandwidth ω_b, which is defined as that frequency where the gain crosses the -3 dB axis.

- The resonance overshoot M_m, which is defined as the maximum value of the gain of the closed-loop system.

The frequency response can be represented as a Bode plot or a Nyquist plot. The diagrams below illustrate the meaning of some of the presented characteristic values (see also [6, 7]).



Time domain characteristic values



Closed-loop frequency domain characteristic values

Remark: If the open-loop system contains a dead time, this dead time is set to zero for calculating the frequency response of the closed-loop system.

Program options

File format

RESY data are saved in files with the SCL extension (*Standard Control Loop*). Nevertheless files with UFK extension created by older versions of RESY can be loaded and will be tranformed to the new file format when saving them for the next time.

Structure of main window

The screenshot below shows a typical main window when using RESY. The display mode can be changed via the DISPLAY submenu and the corresponding menu item or the corresponding group of toolbar buttons. Available modes are:

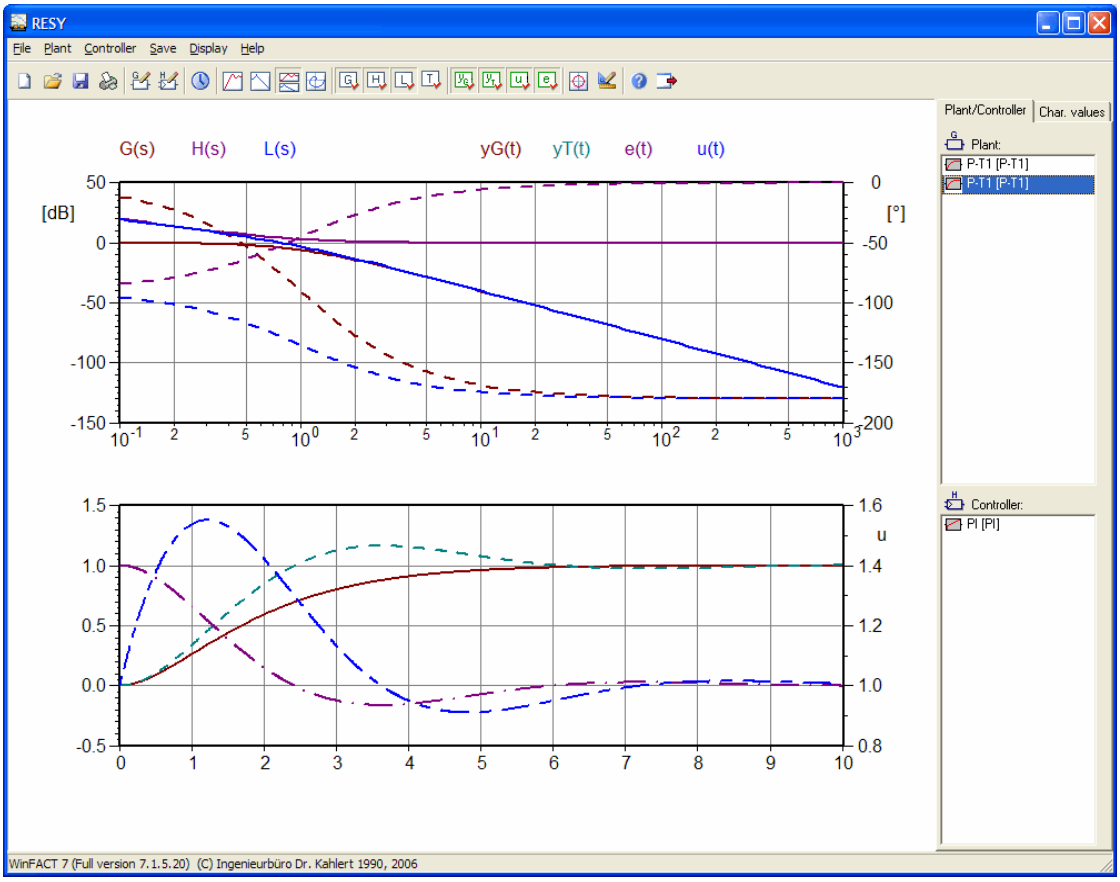
- Full-size display of time domain,
- full-size display of frequency domain (Bode plot or Nyquist plot),
- simultaneous display of time and frequency domain (default).

The selection of the time resp. frequency responses to be displayed can be made via the DISPLAY | OPTIONS... menu option or the corresponding toolbar button group. Displayed by default are

- $G(s)$, $H(s)$ and $L(s)$ for the frequency domain,
- the step response $y_G(t)$ of the plant and the step response $y_T(t)$ of the closed-loop system for the time domain.

If the *Nyquist plot* mode is selected only $L(s)$ is displayed. In this mode the button forces a "really circular" unit circle independent of the window resolution and size.

Coordinate axes scaling is adjusted via the FILE | FREQUENCY RANGE... resp. FILE | SIMULATION PARAMETERS... menu item.

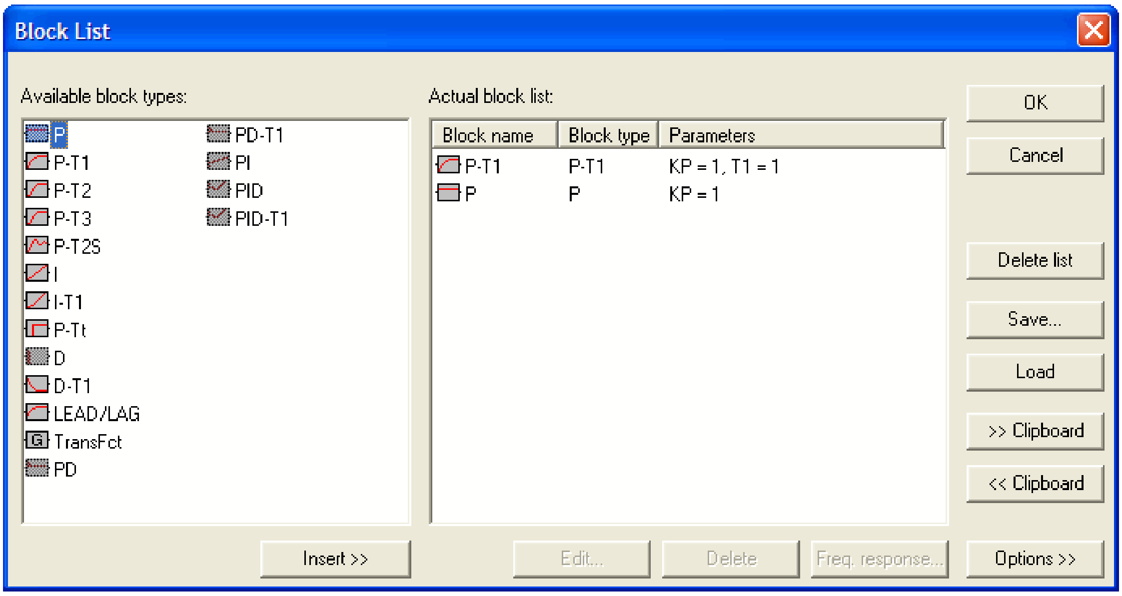


Main window of RESY (time and frequency domain displayed here)

At the right window margin a panel with two palettes is located. The first palette *Plant/Controller* contains two lists displaying the current plant resp. controller blocks. The second palette titled *Char. values* displays all time and frequency domain characteristic values of the open and closed-loop system.

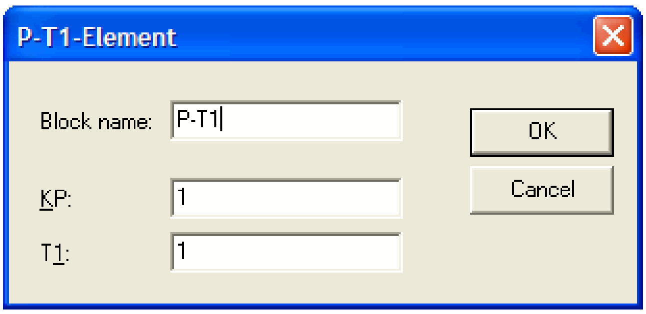
Configuring the control loop

To configure the control loop first the plant has to be specified. For this purpose use the PLANT | EDIT PLANT... menu item or the  toolbar button. The following dialog box appears.



Dialog for plant specification

The left dialog area contains a list view with all available block types; a block can be inserted into the current block list by a double click or by selecting the block first and pressing the *Insert >>* button afterwards. The right area of the dialog shows the current block list in which all blocks are displayed with their block name, block type and parameters. By a double click on a block of the current block list this block can be edited (see screenshot below). Pressing the *Freq. response* button opens a separate window displaying the Bode plot of the selected block. The buttons located at the right dialog margin allow saving and loading of block list files (extension BL) or data transfer from/to the Windows clipboard.



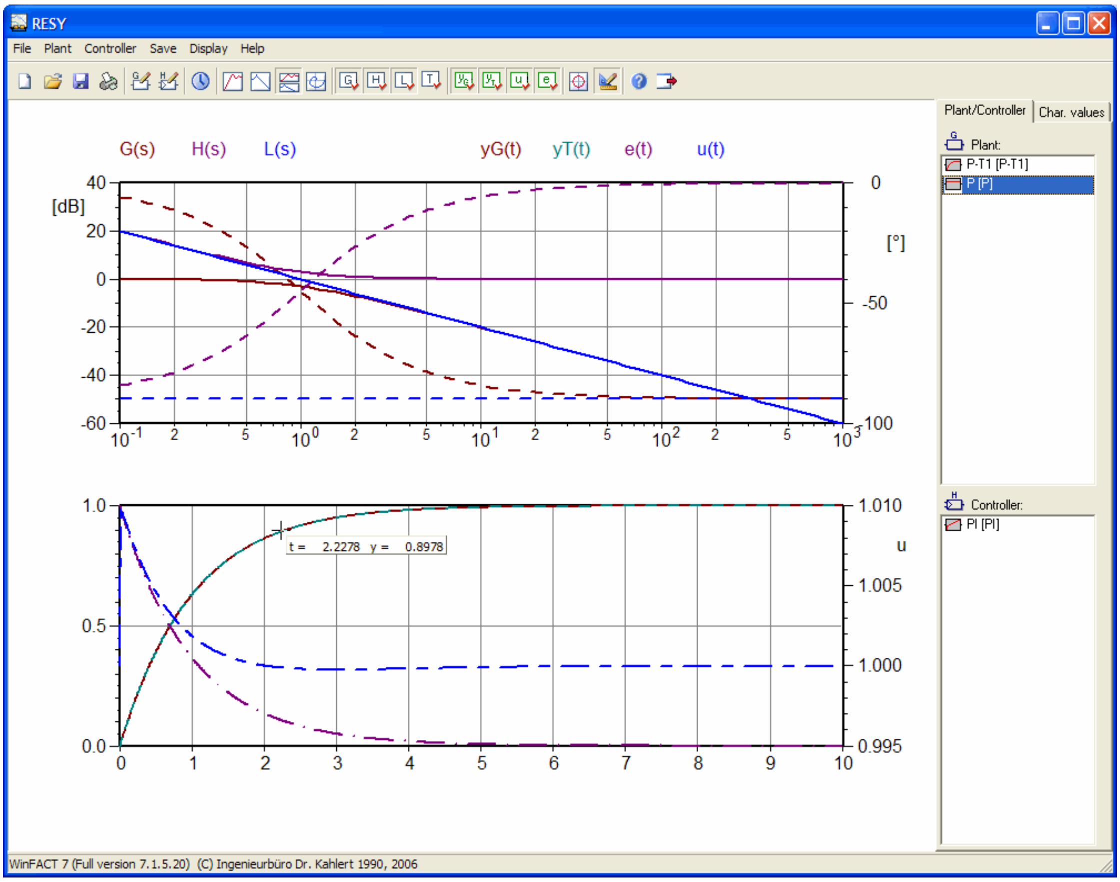
Example: Dialog for editing a P-T1-block

The configuration of the controller is made in an analog way via the CONTROLLER | EDIT CONTROLLER... menu item resp. the toolbar button. Afterwards plant and controller are displayed within the two listboxes at the right window margin. Single blocks can be modified directly within these lists by a double click with the left mouse key or a single click with the right one and the following popup menu.

Remark: As long as not at least one controller block had been inserted the controller is internally handled as a P-controller with a gain of 1.

Measurement mode

The DISPLAY | ACTIVATE MEASUREMENT MODE menu option resp the tool-bar button activate the measurement mode. If this mode is activated the mouse cursor is followed by a small hint window (tooltip) containing the diagram coordinates of the current cursor position.



Program window with activated measurement mode

Saving results

The SAVE submenu allows saving of all relevant results to corresponding files. These are

- the transfer functions $H(s)$, $L(s)$ and $T(s)$ to files of UFK type,
- the step responses $y_{\mathrm{G}}(t)$ and $y_{\mathrm{T}}(t)$ to files of SIM type,
- the frequency responses $H(\mathrm{j}\omega), G(\mathrm{j}\omega), L(\mathrm{j}\omega)$ and $T(\mathrm{j}\omega)$ to files of BD resp. OK type (depending on the current display mode)

Program constants

Maximum order of open-loop system:	20
Maximum number of simulation steps:	unlimited

Sample application

For a plant with the transfer function

$$G(s) = \frac{0.712}{s^2 + 4.27s + 0.712}$$

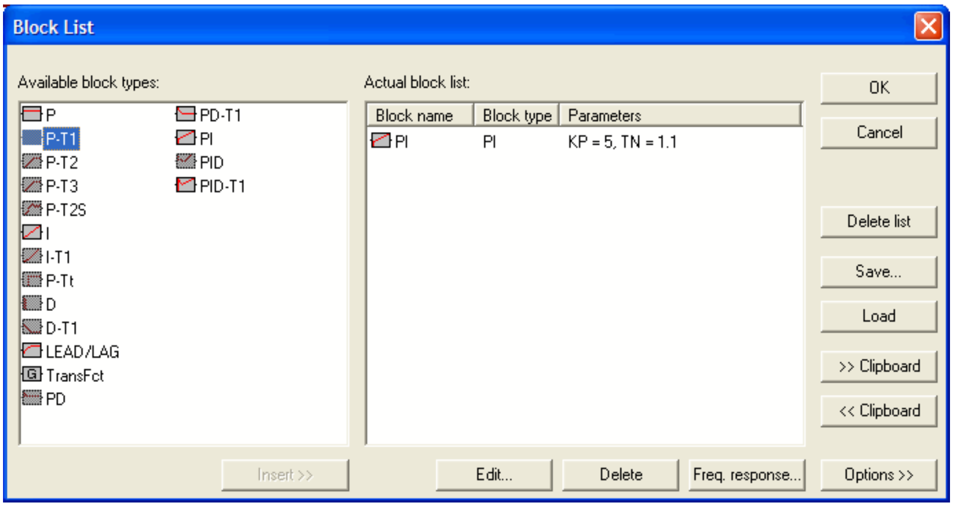
a PI-controller has to be defined that results in the following specification for the open loop frequency response $L(\mathrm{j}\omega)$:

- The gain crossover frequency has to be $\omega_{\mathrm{c}} \approx 1$.
- The phase margin has to be $\Phi_{\mathrm{r}} \approx 45°$.

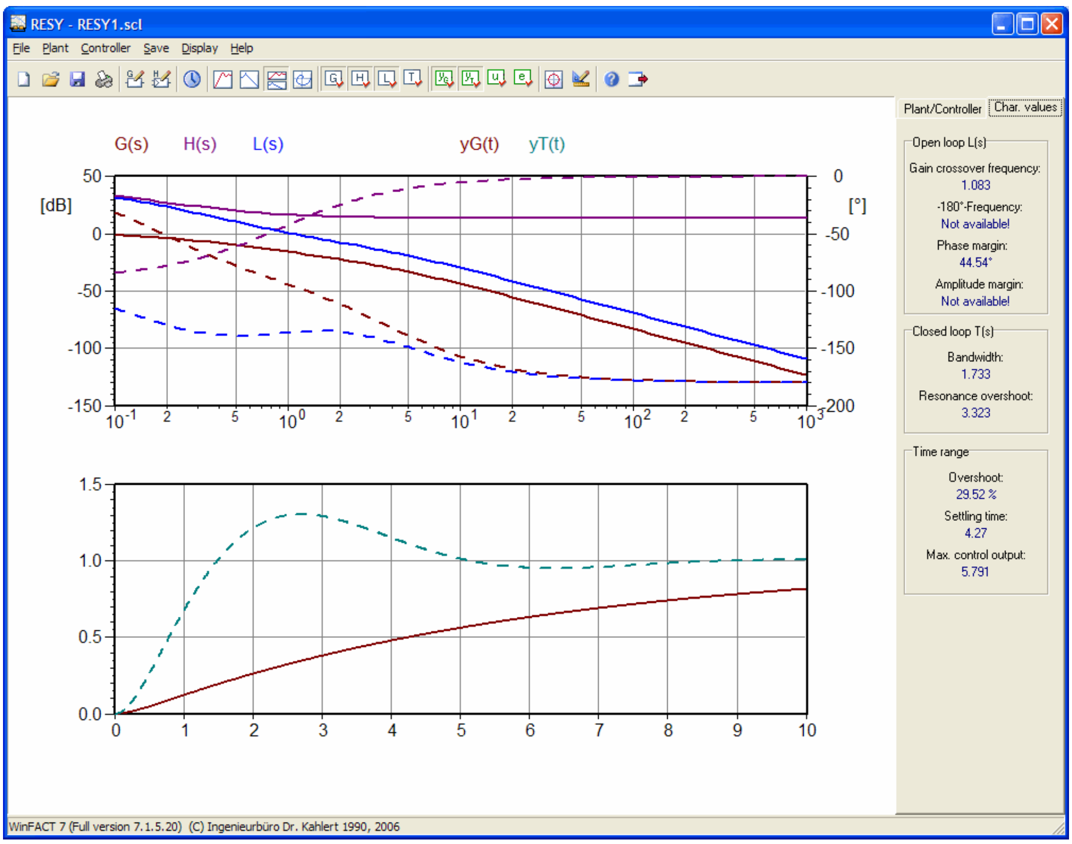
The design delivers the following PI-parameters

$$K_{\mathrm{R}} = 5, \quad T_{\mathrm{N}} = 1.1$$

The screenshots below demonstrate the design of the controller and show the main window of RESY after inserting it to the closed loop. The characteristic value determination delivers an overshoot of about 30%, a settling time of 4.3 and a maximum control output of 5.8. The sample file RESY1.SCL is located in the WinFACT Examples-directory.



Configuring the PI-controller



Design of a PI-controller for a plant of second order