Chapter 10

Tuning of PID controllers

10.1 Introduction

This chapter describes several methods for tuning of controller parameters in PID controllers, that is, methods for finding proper values of K_p, T_i and T_d.

Some of the methods – the Good Gain method[1], and the Ziegler-Nichols' method – are experimental, that is, they require experiments to be made on the process to be controlled. If you have a mathematical process model, you can of course use these experimental methods on a simulator based on the model.

One method – Skogestad's method – is model-based, i.e. you can get good PID parameter values directly from the transfer function model of the process, without doing any experiment. Still, you should verify that the PID tuning is proper by simulating.

What is the aim of the controller tuning? If it was possible to obtain, we would like to obtain both of the following for the control system:

- Fast responses, and
- Good stability

Unfortunately, for practical systems these two wishes can not be achieved simultaneously. In other words:

[1] I am responsible of this name.

- The faster response, the worse stability, and
- The better stability, the slower response.

So, for the control system, we look for the following compromise:

Acceptable stability, and medium fastness of response

Figure 10.1 illustrates the two mutual excluding wishes presented above, and the compromise. The figure shows the response in the process output variable due to a step change of the setpoint. (The responses are with three different controller gains in a simulated control system.) It is useful to have this compromise in mind when you perform controller tuning.

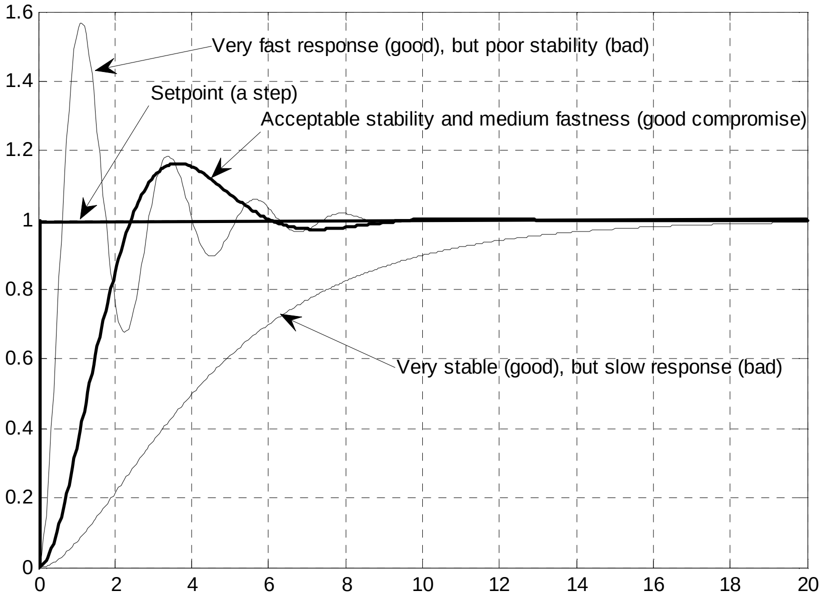

Figure 10.1: In controller tuning we want to achieve this compromise: Acceptable stability and medium fastness of response.

What is "acceptable stability" more specifically? There exists no single definition. One simple yet useful definition is as follows. Assume a positive step change of the setpoint.

Acceptable stability is when the undershoot that follows the first overshoot of the response is small, or barely observable.

(If the step change is negative, the terms undershoot and overshoot are interchanged, of course.) The response shown with thick line in Figure 10.1 is representative for acceptable stability.

As an alternative to observing the response after a step change of the setpoint, you can regard the response after a step change of the process disturbance. The definition of acceptable stability is the same as for the setpoint change, i.e. that the undershoot (or overshoot – depending on the sign of the disturbance step change) that follows the first overshoot (or undershoot) is small, or barely observable.

10.2 Good Gain method

The Good Gain method[2] is a simple method which seems to give good results on the lab and on simulators. The method is based on experiments on a real or simulated control system, see Figure 10.2. (A benefit of the method as compared to the Ziegler-Nichols' closed loop method, cf. Section 10.3, is that it does not require the control system to be brought into sustained oscillations in the tuning phase.) The procedure described below assumes a PI controller, which is the most commonly used controller function (more common than the P controller and the PID controller).

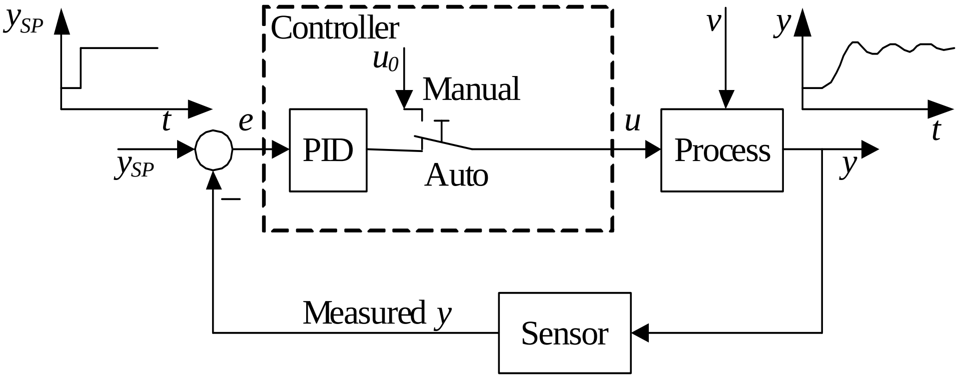

Figure 10.2: The Good Gain method for PID tuning is applied to the established control system.

[2] I am responsible for this name.

However, a comment about how to include the D-term, so that the controller becomes a PID controller, is also given.

1. Bring the process to or close to the normal or specified operation point by adjusting the nominal control signal u_0 (with the controller in manual mode).

2. Ensure that the controller is a P controller with $K_p = 0$ (set $T_i = \infty$ and $T_d = 0$). Increase K_p until the control loop gets satisfactory stability as seen in the response in the measurement signal after e.g. a step in the setpoint or in the disturbance (exciting with a step in the disturbance may be impossible on a real system, but it possible in a simulator). If you do not want to start with $K_p = 0$, you can try $K_p = 1$ (which is a good initial guess in many cases) and then increase or decrease the K_p value until you observe a slight overshoot but a well damped response.

3. Set the integral time T_i equal to

$$T_i = 1.5T_{ou} \tag{10.1}$$

where T_{ou} is the time between the first overshoot and the first undershoot of the step response (a step in the setpoint) with the P controller, see Figure 10.3.

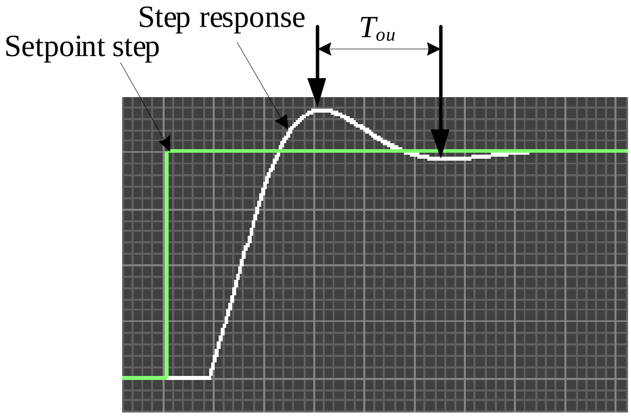

Figure 10.3: Reading off the time between the first overshoot and the first undershoot of the step response with P controller

4. Check the stability of the control system by applying a setpoint step. Because of the introduction of the I-term, the loop with the PI controller in action will probably have somewhat reduced stability

than with the P controller only. If you think that the stability has become too poor, try reducing K_p somewhat, e.g. reduce it to 80% of the original value.

5. If you want to include the D-term, so that the controller becomes a PID controller[3], you can try setting T_d as follows:

$$T_d = \frac{T_i}{4} \tag{10.2}$$

which is the T_d–T_i relation that was used by Ziegler and Nichols, cf. Section 10.3.

Example 10.1 ***PI controller tuning of a wood-chip level control system with the Good Gain Method***

I have used the Dummies method on a simulator of the level control system for the wood-chip tank, cf. Figure 7.2 with parameters (7.1) – (7.9). The PI parameter values became

$$K_p = 1.4;\ T_i = 1100\text{ s};\ T_d = 0\text{ s} \tag{10.3}$$

Figure 10.4 shows the resulting responses. The control system seems to have satisfactory stability. (I did not reduce the K_p value, cf. item 4 above.)

[End of Example 10.1]

10.3 Ziegler-Nichols' closed loop method

10.3.1 Introduction

Ziegler and Nichols published in 1942 a paper [8] where they described two methods for tuning the parameters of P-, PI- and PID controllers. These two methods are the *Ziegler-Nichols' closed loop method*[4], and the *Ziegler-Nichols' open loop method*[5]. Of these methods the closed-loop method is the most useful, and it is described below. The open-loop method is not described here.

[3] But remember the drawbacks about the D-term, namely that it amplifies the measurement noise, causing noisy controller signal.

[4] Also denoted the *Ultimate gain method.*

[5] Or the *Process reaction curve method*

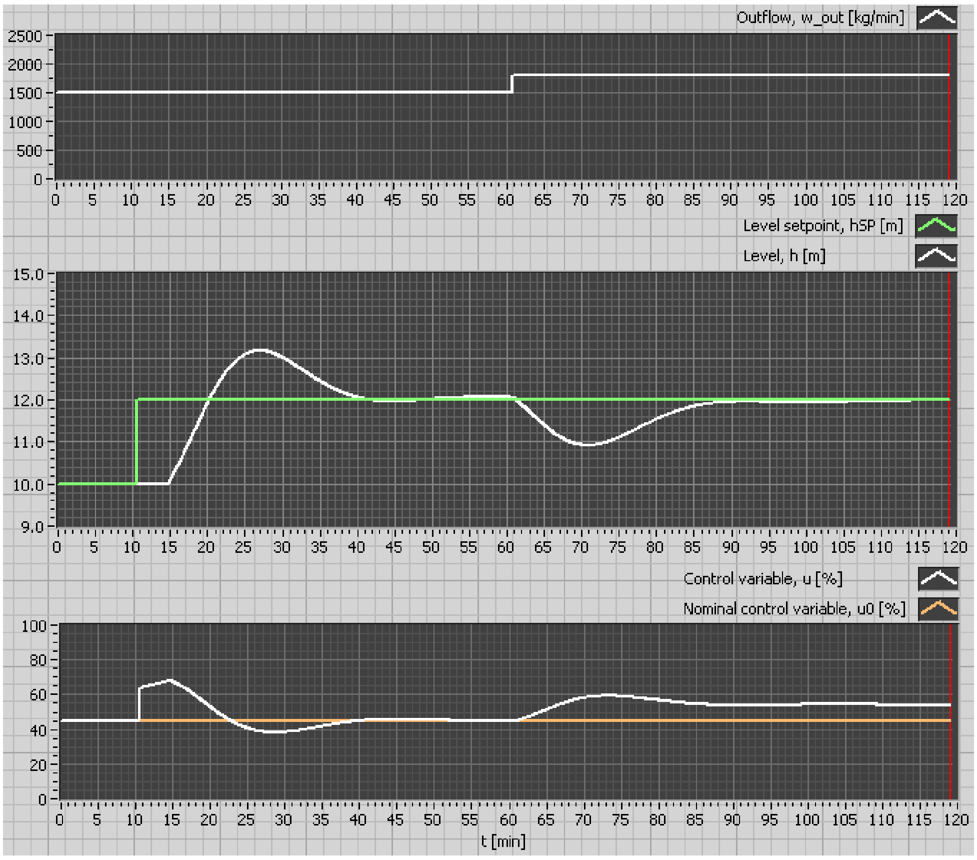

Figure 10.4: Example 10.1: Level control of the wood-chip tank with a PI controller.

Ziegler and Nichols [8] used the following definition of acceptable stability as a basis for their contoller tuning rules: The ratio of the amplitudes of subsequent peaks in the same direction (due to a step change of the disturbance or a step change of the setpoint in the control loop) is approximately 1/4, see Figure 10.5:

$$\frac{A_2}{A_1} = \frac{1}{4} \tag{10.4}$$

However, there is no guaranty that the actual amplitude ratio of a given control system becomes 1/4 after tuning with one of the Ziegler and Nichols' methods, but it should not be very different from 1/4.

This definition of acceptable stability implies worse stability than the definition given in Section 10.1 of this chapter. It has actually become common point of view that the 1/4 decay ratio of the step response

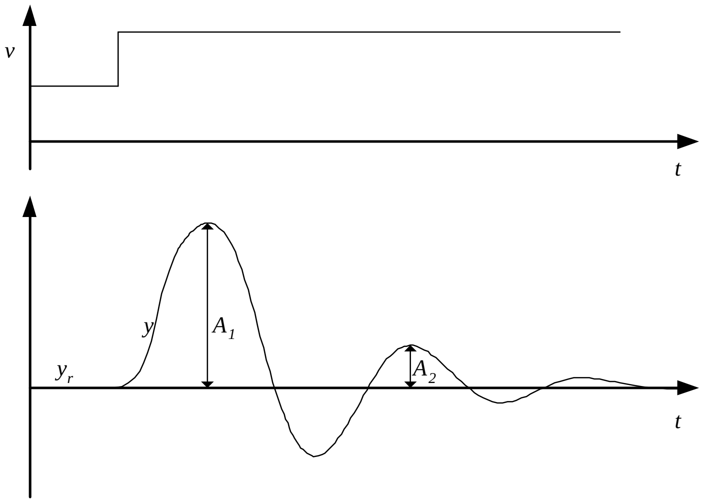

Figure 10.5: If $A_2/A_1 \approx 1/4$ the stability of the system is ok, according to Ziegler and Nichols

corresponds too poor stability of the control loop. If you think that the stability of the control loop becomes too poor, you can try to adjust the controller parameters. The first aid, which may be the only adjustment needed, is to decrease K_p somewhat, for example a 20% decrease.

It is also important to remember the impact of the measurement noise on the control signal. The more aggressive controller – fast control – the more sensitive is the control signal to the measurement noise. Again, to descrease this sensitivity, the controller gain can be descreased.

Note that the Ziegler-Nichols' closed loop method can be applied only to processes having a time delay or having dynamics of order higher than 3. Here are a few examples of process transfer function models for which the method can *not* be used:

$$H(s) = \frac{K}{s} \qquad \text{(integrator)} \tag{10.5}$$

$$H(s) = \frac{K}{Ts+1} \qquad \text{(first order system)} \tag{10.6}$$

$$H(s) = \frac{K}{(\frac{s}{\omega_0})^2 + 2\zeta\frac{s}{\omega_0} + 1} \qquad \text{(second order system)} \tag{10.7}$$

Controller tuning for processes as above can be executed with a transfer function based method, cf. Section 10.6. For the second order system the Good Gain Method can also be used.

10.3.2 The Ziegler-Nichols' PID tuning procedure

The Ziegler-Nichols' closed loop method is based on experiments executed on an established control loop (a real system or a simulated system), see Figure 10.6.

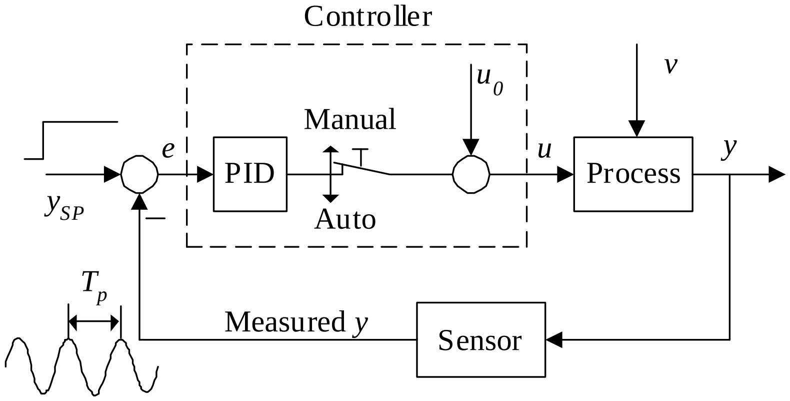

Figure 10.6: The Ziegler-Nichols' closed loop method is executed on an established control system.

The tuning procedure is as follows:

1. Bring the process to (or as close to as possible) the specified *operating point* of the control system to ensure that the controller during the tuning is "feeling" representative process dynamic[6] and to minimize the chance that variables during the tuning reach limits. You can bring the process to the operating point by manually adjusting the control variable, with the controller in manual mode, until the process variable is approximately equal to the setpoint.

2. Turn the PID controller into a *P controller* by setting set $T_i = \infty$[7] and $T_d = 0$. Initially set gain $K_p = 0$. Close the control loop by setting the controller in automatic mode.

3. Increase K_p until there are *sustained oscillations* in the signals in the control system, e.g. in the process measurement, after an excitation of the system. (The sustained oscillations corresponds to the system

[6] This may be important for nonlinear processes.

[7] In some commercial controllers $T_i = 0$ is a code that is used to deactivate the I-term, corresponding to $T_i = \infty$.