Article:

The Good Gain method for PI(D) controller tuning

Finn Haugen
TechTeach
(http://techteach.no)

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1 Introduction

The Good Gain method[1] is a simple, experimental method which can be used on a real process (without any knowledge about the process to be controlled), or simulated system (in this case you need a mathematical model of the process, of course), see Figure 1.

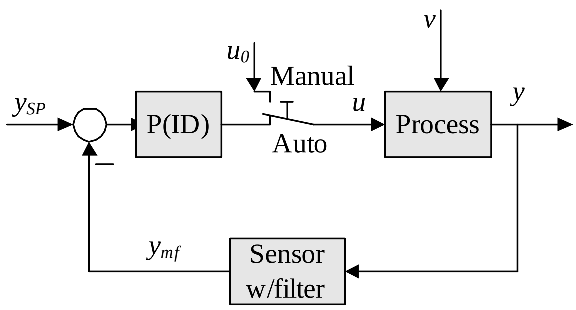

Figure 1: The Good Gain method for PID tuning is applied to the established control system.

The Good Gain method aims at giving the control loop better stability than what the famous Ziegler-Nichols' methods – the Closed-loop method and the Open-loop method [3] – gives. The Ziegler-Nichols' methods are designed to give an amplitude ratio between subsequent oscillations after a step change of the setpoin equal to 1/4 ("one-quarter decay ratio"). This is often regarded as poor stability. The Good Gain method gives better stability. Furthermore, the Good Gain method does not require the control

[1] The method is developed by the author.

loop to get into oscillations during the tuning, which is another benefit compared with the Ziegler-Nichols' methods.

2 Tuning procedure

The procedure described below assumes a PI controller, which is the most commonly used controller function. 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 good (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 is 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 some overshoot and a barely observable undershoot (or vice versa if you apply a setpoint step change the opposite way, i.e. a negative step change), see Figure 2. This kind of response is assumed to represent good stability of the control system. This gain value is denoted K_{pGG}.

   It is important that *the control signal is not driven to any saturation limit* (maximum or minimum value) during the experiment. If such limits are reached the K_p value may not be a good one – probably too large to provide good stability when the control system is in normal operation. So, you should apply a relatively small step change of the setpoint (e.g. 5% of the setpoint range), but not so small that the response drowns in noise.

3. Set the integral time T_i equal to

   $$\underline{T_i = 1.5 T_{ou}} \tag{1}$$

   where T_{ou} is the time between the <u>o</u>vershoot and the <u>u</u>ndershoot of the step response (a step in the setpoint) with the P controller, see

Figure 2.[2] Note that for most systems (those which does not containt a pure integrator) there will be offset from setpoint because the controller during the tuning is just a P controller.

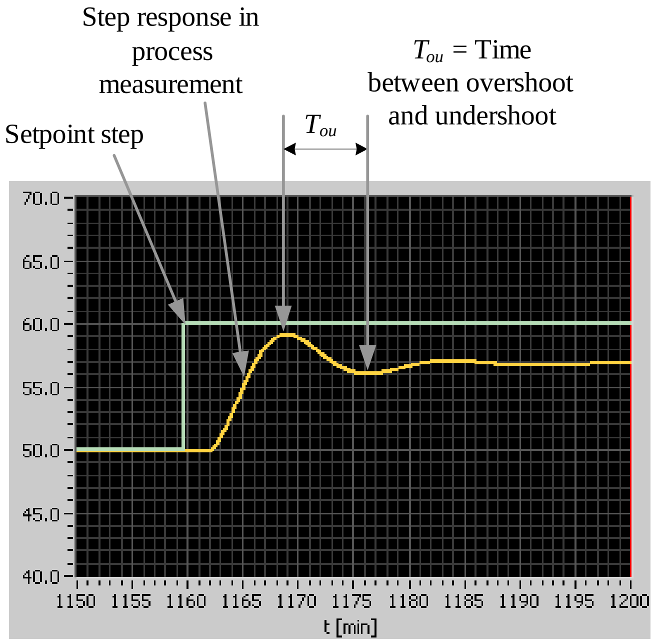

Figure 2: The Good Gain method: Reading off the time between the overshoot and the undershoot of the step response with P controller

4. 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. To compensate for this, the K_p can be reduced somewhat, e.g. to 80% of the original value. Hence,

$$\underline{K_p = 0.8K_{pGG}} \tag{2}$$

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:

$$T_d = \frac{T_i}{4} \tag{3}$$

which is the T_d–T_i relation that was used by Ziegler and Nichols [3].

[2] Alternatively, you may apply a negative setpoint step, giving a similar response but downwards. In this case T_{ou} is time between the undershoot and the overshoot.

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

6. You should check the stability of the control system with the above controller settings by applying a step change of the setpoint. If the stability is poor, try reducing the controller gain somewhat, possibly in combination with increasing the integral time.

Eksempel 1 ***PI controller tuning of a wood-chip level control system with the Good Gain Method***

I have tried the Ziegler-Nichols' closed loop method on a level control system for a wood-chip tank with feed screw and conveyor belt which runs with constant speed, see Figure 3.[4] [5] The purpose of the control system is to keep the chip level of the tank equal to the actual, measured level.

The level control system works as follows: The controller tries to keep the measured level equal to the level setpoint by adjusting the rotational speed of the feed screw as a function of the control error (which is the difference between the level setpoint and the measured level).

During the tuning I found

$$K_{pGG} = 1.5 \tag{4}$$

and

$$T_{ou} = 12 \text{ min} \tag{5}$$

The PI parameter values are

$$K_p = 0.8K_{pGG} = 0.8 \cdot 1.5 = 1.2 \tag{6}$$

$$T_i = 1.5T_{ou} = 1.5 \cdot 12 \text{ min} = 18 \text{ min} = 1080 \text{ s} \tag{7}$$

Figure 4 shows the resulting responses with a setpoint step at time 20 min and a disturbance step (outflow step from 1500 to 1800 kg/min) at time 120 min. The control system has good stability.

[End of Example 1]

3 Theoretical background

In the Good Gain method the process is controlled with a P-controller, and the step response in the process output due to a step in the setpoint is

[4] This example is based on an existing system in the paper pulp factory Södra Cell Tofte in Norway. The tank with conveyor belt is in the beginning of the paper pulp production line.

[5] A simulator of the system is available at http://techteach.no/simview.

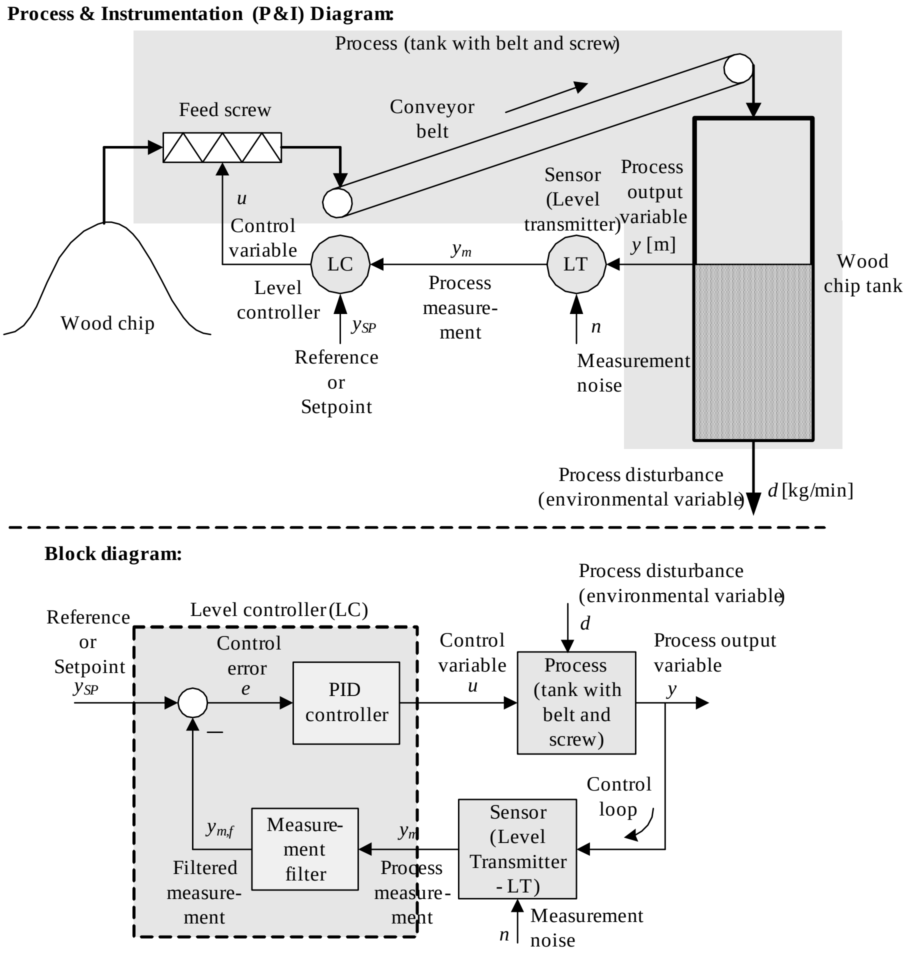

Figure 3: P&I (Process and Instrumentation) diagram and block diagram of a level control system for a wood-chip tank in a pulp factory

well-damped oscillations. Let's assume that the control loop behaves approximately as an underdamped second order system with the following transfer function model from setpoint to process output:

$$\frac{y(s)}{y_{SP}(s)} = \frac{K\omega_0^2}{s^2 + 2\zeta\omega_0 s + \omega_0^2} \tag{8}$$

It can be shown that with $\zeta = 0.6$ the step response is damped oscillations with an overshoot of about 10% and a barely observable undershoot, as in

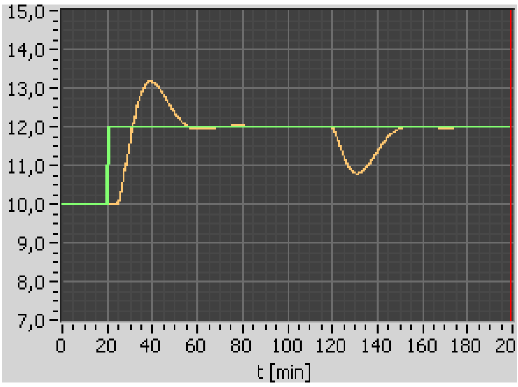

Figure 4: Example 1: Level control of the wood-chip tank with a PI controller.

the Good Gain tuning, and that the period of the damped oscillations is

$$P_d = \frac{2\pi}{\sqrt{1-\zeta^2}\omega_0} = \frac{2\pi}{\sqrt{1-0.6^2}\omega_0} \tag{9}$$

$$= \frac{2\pi}{0.8\omega_0} = P_{GG} = 2T_{ou} \tag{10}$$

If the oscillations are undamped, as with the Ziegler-Nichols' Ultimate Gain method, the period of the oscillations is

$$P_{ZN} = \frac{2\pi}{\omega_0} \tag{11}$$

Hence, the relation between the period of the damped oscillations of the Good Gain method and the undamped oscillations of the Ziegler-Nichols' method is approximately

$$P_{ZN} = 0.8P_{GG} = 1.6T_{ou} \tag{12}$$

In the Ziegler-Nichols' method we set

$$T_i = \frac{P_{ZN}}{1.2} = \frac{1.6T_{ou}}{1.2} = 1.33T_{ou} \tag{13}$$

If we make the T_i setting somewhat more relaxed (to obtain better stability and better robustness), we can increase T_i to

$$\underline{T_i = 1.5T_{ou}} \tag{14}$$

In the Ziegler-Nichols' method the controller gain K_c of a PI-controller is 90% of the gain of the P-controller. To compensate for the inclusion of the integral term we can reduce the original controller gain of the Good Gain method to 90%, but to relax the setting even more, let's set

$$\underline{K_c = 0.8K_{cGG}} \tag{15}$$

Note that the Good Gain method can *not* be used if the process transfer function (from control signal u to filtered process measurement y_{mf}) is one of the following:

- Integrator without delay:

$$H_p(s) = \frac{y_{mf}(s)}{u(s)} = \frac{K}{s} \tag{16}$$

- Time-constant without time-delay:

$$H_p(s) = \frac{K}{Ts+1} \tag{17}$$

This is because with the above process models, there will be no oscillations in the response in the process output due to a step in the setpoint, with a P-controller.

One example of an integrator without time-delay is a liquid tank where level is to be controlled and the controller adjusts the inflow, and there is outflow via a pump. If the outflow is via a valve, the model will approximately be a time-constant transfer function.

For processes like (16) and (17) you can tune the controller with Skogestad's method [2], which is summarized in the text-book Basic Dynamics and Control [1].

References

[1] Haugen, F.: *Basic Dynamics and Control*, TechTeach (http://techteach.no) 2010

[2] Skogestad, S.: *Simple Analytical Rules for Model Reduction and PID Controller Tuning*, J. Process Control, Vol. 13, 2003

[3] Ziegler, J. G. and Nichols, N. B.: *Optimum Settings for Automatic Controllers,* Trans. ASME, Vol. 64, 1942, s. 759-768