Article:
Ziegler-Nichols' Closed-Loop Method

Finn Haugen
TechTeach

17. July 2010

1 Introduction

Ziegler and Nichols published in 1942 a paper [1] 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*[1], and the *Ziegler-Nichols' open loop method*[2]. The present article describes the closed-loop method, while the open-loop method is described in another article (available at http://techteach.no).

Ziegler and Nichols [1] 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 1:

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

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.

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:

$$H(s) = \frac{K}{s} \qquad \text{(integrator)} \tag{2}$$

$$H(s) = \frac{K}{Ts+1} \qquad \text{(first order system)} \tag{3}$$

$$H(s) = \frac{K}{(\frac{s}{\omega_0})^2 + 2\zeta\frac{s}{\omega_0} + 1} \qquad \text{(second order system)} \tag{4}$$

[1] Also denoted the *Ultimate gain method.*
[2] Or the *Process reaction curve method*

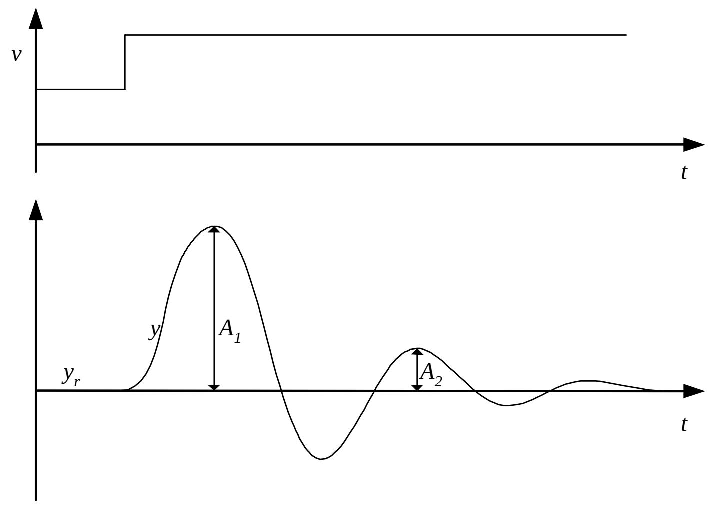

Figure 1: If $A_2/A_1 \approx 1/4$ the stability of the system is ok, according to Ziegler and Nichols

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 2.

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[3] 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 $T_i = \infty$[4] and $T_d = 0$. Initially set gain $K_p = 0$. Close the control loop by setting the controller in automatic mode.

[3] This may be important for nonlinear processes.

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

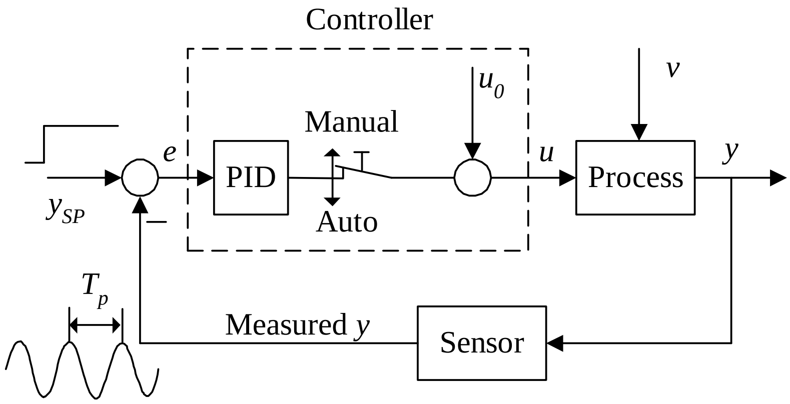

Figure 2: The Ziegler-Nichols' closed loop method is executed on an established control system.

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 being on the stability limit.) This K_p value is denoted the *ultimate (or critical) gain*, K_{p_u}.

   The excitation can be a step in the setpoint. This step must be small, for example 5% of the maximum setpoint range, so that the process is not driven too far away from the operating point where the dynamic properties of the process may be different. On the other hand, the step must not be too small, or it may be difficult to observe the oscillations due to the inevitable measurement noise.

   It is important that K_{p_u} is found *without the control signal being driven to any saturation limit* (maximum or minimum value) during the oscillations. If such limits are reached, you will find that there will be sustained oscillations for any (large) value of K_p, e.g. 1000000, and the resulting K_p-value (as calculated from the Ziegler-Nichols' formulas, cf. Table 1) is useless (the control system will probably be unstable). One way to say this is that K_{p_u} must be the smallest K_p value that drives the control loop into sustained oscillations.

4. Measure the *ultimate (or critical) period* P_u of the sustained oscillations.

5. *Calculate the controller parameter values* according to Table 1, and use these parameter values in the controller.

   If the stability of the control loop is poor, try to improve the stability by decreasing K_p, for example a 20% decrease.

	K_p	T_i	T_d
P controller	$0.5K_{p_u}$	∞	0
PI controller	$0.45K_{p_u}$	$\frac{P_u}{1.2}$	0
PID controller	$0.6K_{p_u}$	$\frac{P_u}{2}$	$\frac{P_u}{8} = \frac{T_i}{4}$

Table 1: Formulas for the controller parameters in the Ziegler-Nichols' closed loop method.

Eksempel 1 ***Tuning a PI controller with the Ziegler-Nichols' closed loop 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.[5] [6] 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).

Figure 4 shows the signals after a step in the setpoint from 9 m to 9.5 m with a ultimate gain of $K_{p_u} = 3.0$. The ultimate period is approximately $P_u = 1100$ s. From Table 1 we get the following PI parameters:

$$K_p = 0.45 \cdot 3.0 = 1.35 \tag{5}$$

$$T_i = \frac{1100 \text{ s}}{1.2} = 917 \text{ s} \tag{6}$$

$$T_d = 0 \text{ s} \tag{7}$$

Figure 5 shows signals of the control system with the above PID parameter values. The control system has satisfactory stability. The amplitude ratio in the damped oscillations is less than 1/4, that is, which means that the stability is a little better than prescribed by Ziegler and Nichols'.

[End of Example 1]

[5] 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.

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

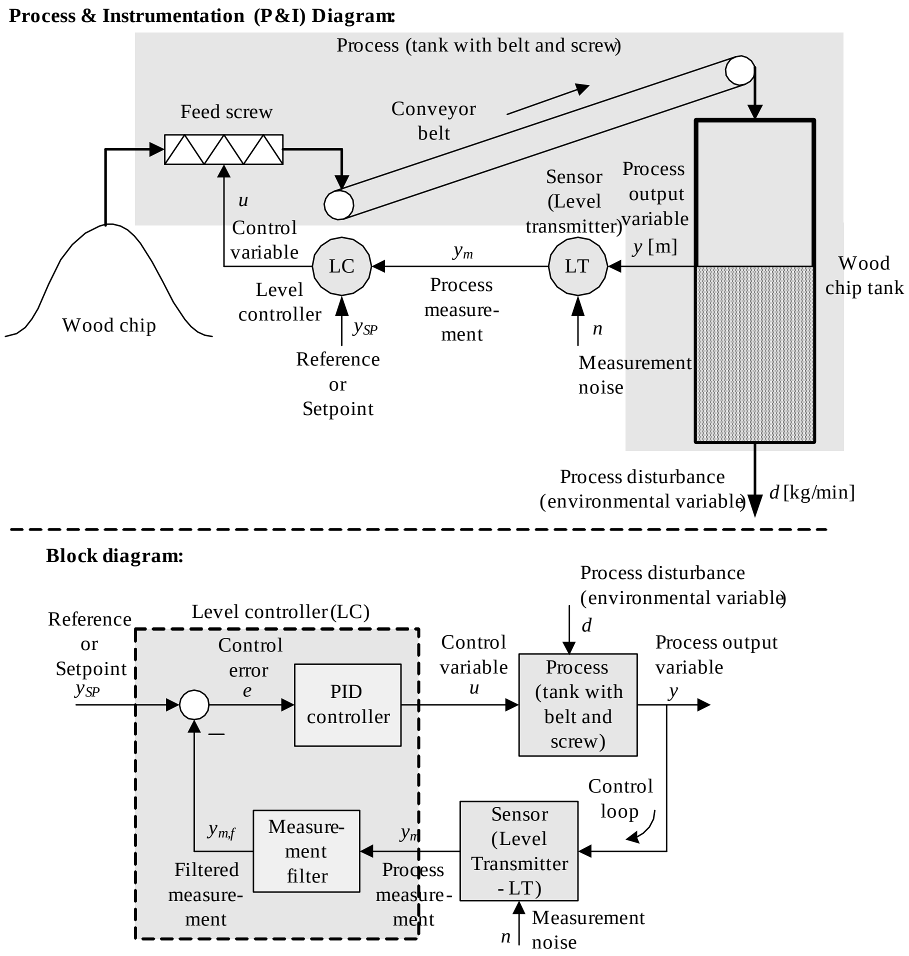

Figure 3: P&I (Process and Instrumentation) diagram and block diagram of a level control system for a wood-chip tank in a pulp factory

3 Some comments to the Ziegler-Nichols' closed loop method

1. *You do not know in advance the amplitude of the sustained oscillations.* The amplitude depends on the size of the excitations of the control system.

2. If the operating point varies and if the process dynamic properties depends on the operating point, you should consider using some kind of *adaptive control or gain scheduling*, where the PID parameter are adjusted as functions of the operating point.

   If the controller parameters shall have fixed value, they should be

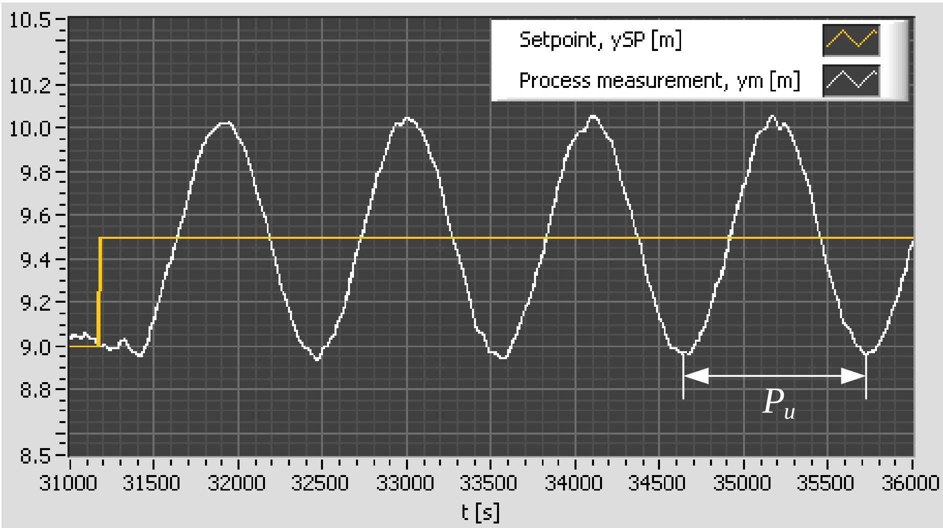

Figure 4: Example 1: The tuning phase of the Ziegler-Nichols' closed-loop method.

tuned in the worst case as stability is regarded. This ensures proper stability if the operation point varies. The worst operating point is the operation point where the process gain has its greatest value and/or the time delay has its greatest value.

3. *The responses in the control system may become unsatisfactory* with the Ziegler-Nichols' method. 1/4 decay ratio may be too much, that is, the damping in the loop is too small. A simple re-tuning in this case is to reduce the K_p somewhat, for example by 20%.

References

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

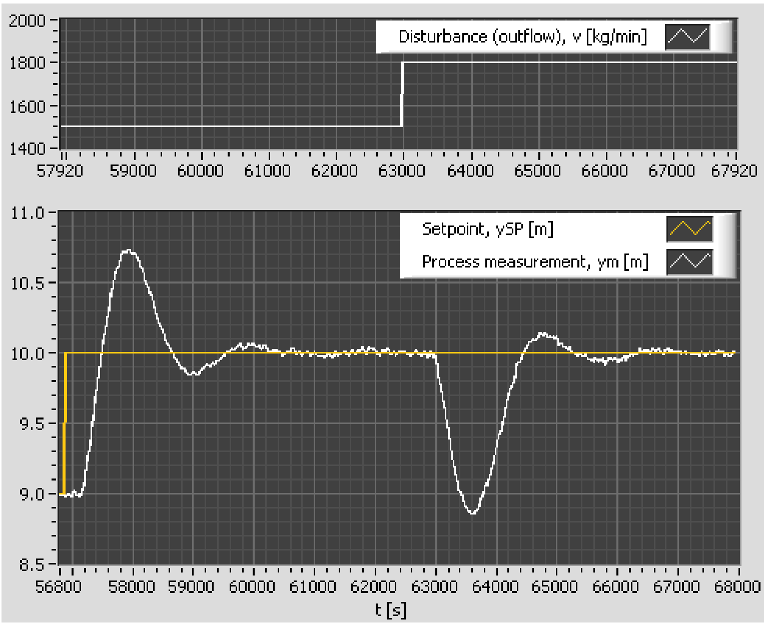

Figure 5: Example 1: Time responses with PI parameters tuned using the Ziegler-Nichols' closed loop method