Article:

Ziegler-Nichols' Open-Loop Method

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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 open-loop method, while the closed-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 where it is possible to read off an apparant time delay in the step-response of the process to be controlled.

2 The Ziegler-Nichols' PID tuning procedure

The Ziegler-Nichols' open loop method is based on the *process step response*. The PID parameters are calculated from the response in the

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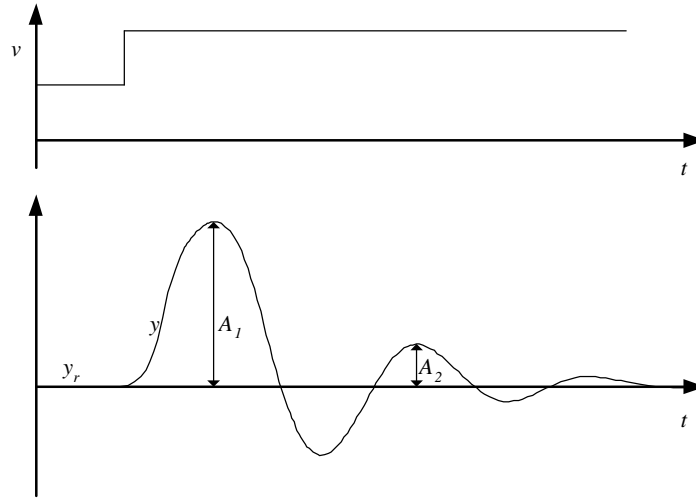[2] Or the *Process reaction curve method*

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

process measurement y_m after a step with height U in the control variable u, see Figure 2. The term "process" here means all blocks in the control except the controller. The step response experiment is executed on the uncontrolled process, so the control loop is open (no feedback).
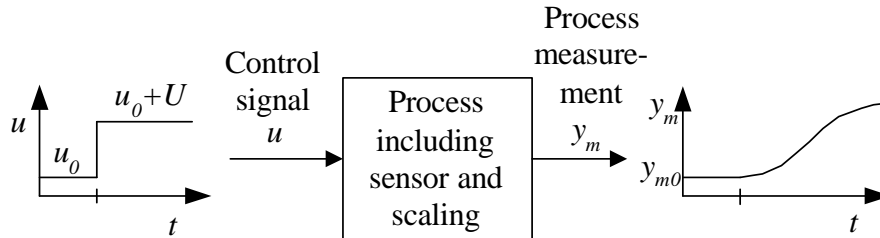

Figure 2: The Ziegler-Nichols' open loop method is based on the step response of the uncontrolled process

The method is as follows.

1. If the control loop is closed (i.e. feedback), the loop must be opened. This can be done by setting the controller in manual mode.

2. Bring the process to the operation point by adjusting the control variable manually. This is done by adjusting u_0 in Figure 2.

3. Excite the process via a step of amplitude U in the control variable u. The step should be "small" so that the process is not brought too far from the operation point, but of course the step must large enough to give an observable response in process measurement y_m. A step amplitude of $U = 10\%$ can be a reasonable value, but the amplitude must be chosen individually in each case.

4. Read off the following characteristic parameters from the step response in y_m:

   - *Equivalent dead-time or lag L*
   - *Rate or slope R*

   Figure 3 which shows the relevant part of a typical step response. In the figure the time axis starts at the step time. The annotation "0.0" along the y-axis corresponds to y_{m0} in Figure 2. L is the time from the step time to the point of intersection between the "0.0"-line and the steepest tangent. R is the slope of the steepest tangent.
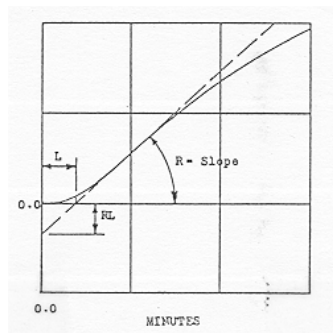

Figure 3: Ziegler-Nichols' open loop method: The equivalent dead-time L and rate R read off from the process step response. (The figure is a reprint from [1] with permission.)

5. Calculate the controller parameters according to Table 1.

6. After the controller parameters have been calculated and entered into the PID controller, the control loop is closed (by setting the controller in automatic mode).

Eksempel 1 *Controller tuning using Ziegler-Nichols' open loop method*

	K_p	T_i	T_d
P controller	$\frac{1}{LR/U}$	∞	0
PI controller	$\frac{0.9}{LR/U}$	$3.3L$	0
PID controller	$\frac{1.2}{LR/U}$	$2L$	$0.5L = \frac{T_i}{4}$

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

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 4.[3] [4] 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).

The step in the control variable is $U = 10\%$ from $u_0 = 45\%$ to 55%. Figure 5 shows the response in the level measurement. We read off

$$L = 4.2 \text{ min} \tag{2}$$

R can be calculated from the slope of the level response. From Figure 5 we will find that the level increases approximately 1.7m during 10min, giving a slope of $R_1 = 1.7/10 = 0.17$m/min. However, the slope R must be expressed in unit %/min. The level sensor transforms $0 - 15$m to $0 - 100\%$, corresponding to a measurement gain of $K_m = 6.67\%$/m. Therefore,

$$R = R_1 K_m = 0.17\text{m/min} \cdot 6.67\%\text{/m} = 1.13\%\text{/min} \tag{3}$$

Using these values for L and R in Table 1 gives the following PID parameters:

$$K_p = 2.52; \; T_i = 8.4\text{min} = 504\text{s}; \; T_d = 2.1\text{min} = 126\text{s} \tag{4}$$

Figure 6 shows simulated responses with the PID controller with these above parameters. There is a step in the setpoint and a step in the disturbance (the outflow). The stability of the control system is on the limit of being acceptable, but this is to be expected with this tuning method.
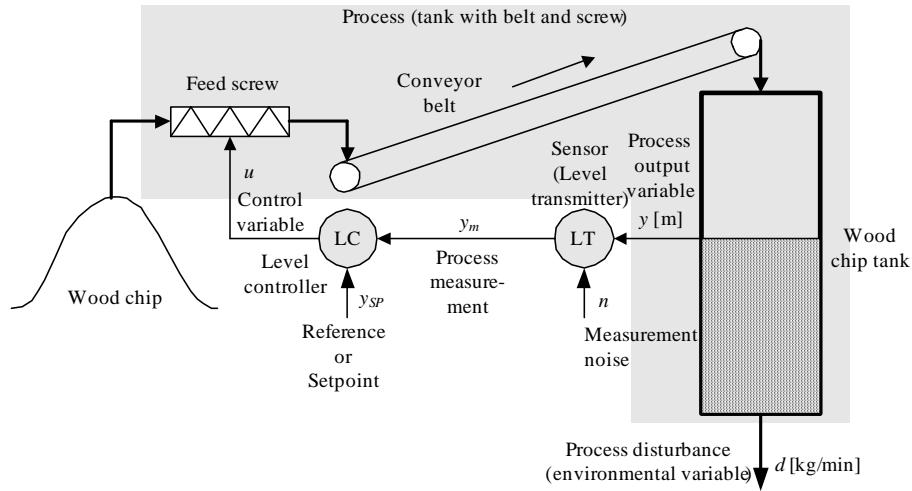
[End of Example 1]

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[3] 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.

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

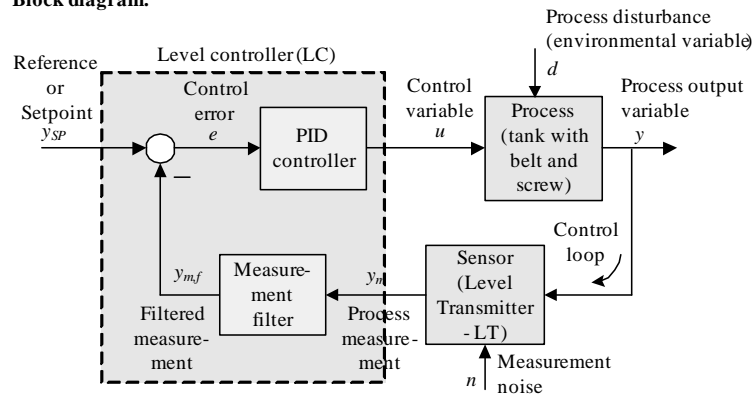**Process & Instrumentation (P&I) Diagram:**

Block diagram:

Figure 4: P&I (Process and Instrumentation) diagram and block diagram of a level control system for a wood-chip tank in a pulp factory

References

[1] J. G. Ziegler and N. B. Nichols: *Optimum Settings for Automatic Controllers,* Trans. ASME, Vol. 64, 1942, s. 759-768
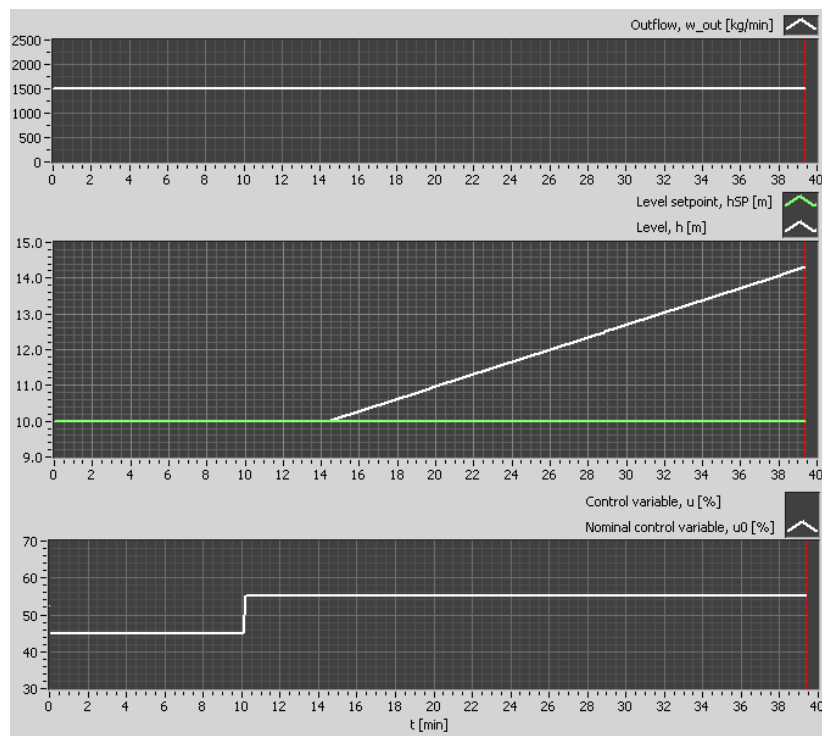
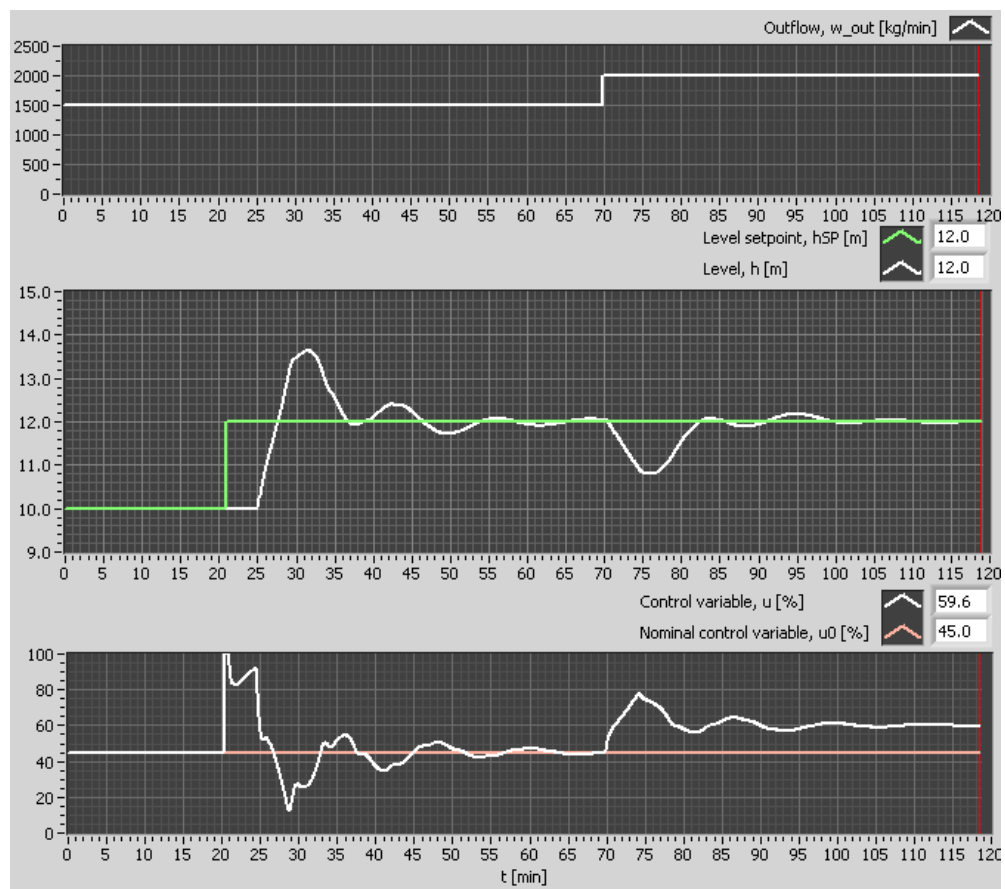Figure 5: Example 1: Ziegler-Nichols' open-loop method applied to the wood-chip tank

Figure 6: Example 1: Time responses with PID parameters tuned using the Ziegler-Nichols' open loop method