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Control Quality Indicators in Controller Autotuning Assessed from Excited Oscillations in a Control Loop

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Abstract: *The development of the autotuning method presented here was motivated by the demands of industrial practice. Industry prefers to use PID controllers and to make experimental settings on-line (mostly with the use of Ziegler and Nichols rules), i.e., a modelless approach. The proposed approach, based on evaluating the frequency responses, uses tools provided by classical linear theory, but it can be applied to control loops with non-linear behaviour. In the theory, a set of quality control indicators usually interpreted by means of a Nyquist plot has been derived. The new idea is to excite a frequency response to small oscillations added to the control error from an external oscillator, and to analyse the response to them from the output of the controlled plant in a closed control loop. This method has an advantage over the Åström and Hägglund relay method: closed loop measurement. This means that the control function is not interrupted while the controller is being set. The paper describes one way of experimentally obtaining the control quality indicators and using them in a new optimal controller parameter setting computation procedure.*

Keywords: *PID controller, oscillation, control quality indicator*

1 Introduction

There are some useful tools for PID controller tuning in linear theory, that can be used in connection with a nonlinear plant. One of these tools represents set of quality control indicators. The well-known indicators are depicted in the Figure 1, when the transfer function of the open control loop is

$$G_o(s) = \frac{0,5s+0,3}{s^3+1,2s^2+s}e^{-1,5s} \tag{1}$$

The indicators are denoted as:

M_s – Maximum Sensitivity

m_A – Gain Margin

γ – Phase Margin

ω_γ – Crossover frequency

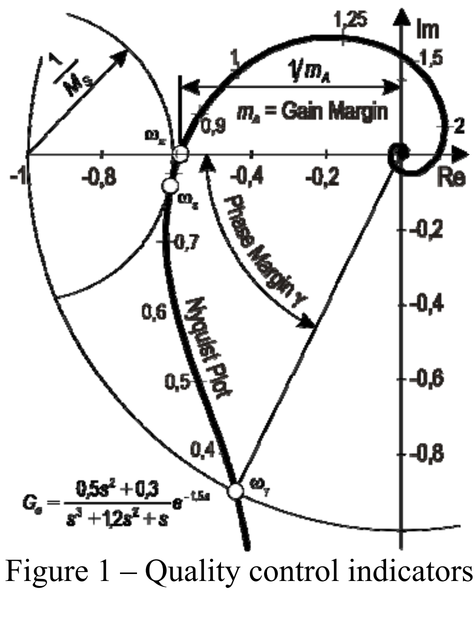

Figure 1 – Quality control indicators

1.1 Other indicators

It is possible to use frequencies ω_π, ω_s and ω_γ as additional indicators when one of the above mentioned indicators is evaluated. However we can define subsequent indicators, like gain, when the phase shift is equal to -120 degrees, or phase shift, when the gain is equal to 0,7. Or we can state, that the Nyquist plot should intersect a linear join of the Phase Margin and the Gain Margin points.

2 Controller autotuning based on control quality indicator evaluation

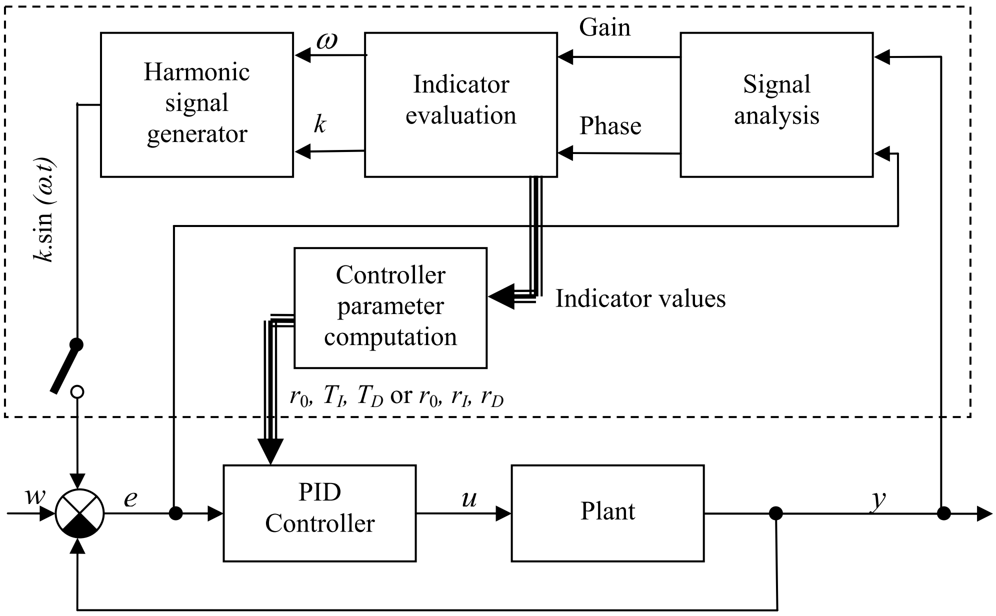

Figure 2 - Control quality indicator autotuning

The principle of control quality indicator evaluation is shown in the Figure 2. The figure depicts a closed control loop and the autotuning mechanism connected to the closed control loop. It can be seen that the controller setting can be changed on demand, or this can be done continuously. The Harmonic signal generator block generates a harmonic signal of variable frequency ω. The Signal analysis block analyses the current characteristics of the control error course, and the controlled value course and the relation between them (gain, phase). The Indicator evaluation block evaluates the actual gain and phase, checks if they are correct, and decides if the change of frequency ω has to be changed or the controller setting has to be changed. If the controller setting has to be changed, the block signals this to the Controller parameter computation block, which computes controller parameter values from the current indicator values.

There are two ways to compute new controller parameter values. The first way is that we strictly specify the values of selected indicators, e. g., the Phase Margin should be equal to 60 degrees (value from the recommended range). Then we start to add harmonic signal $k.\sin(\omega.t)$ to control error e. This causes oscillation in the control loop. The oscillation frequency ω makes the phase shift equal to -120 degrees. Then we measure the gain. If the gain is not equal to one, the controller parameters are changed. Then we have to change the frequency of the added harmonic signal ω to the phase shift stay equal to -120 degrees and measure the gain again. These actions are repeated until the measured gain is equal to one. If the measured gain is equal to one, the desired Phase Margin has been found. We can use a similar procedure to Gain Margin evaluation. The difference is that we set the frequency so that the gain is equal to its desired value and the phase shift is measured. However there is no similar procedure to Maximum Sensitivity evaluation, because there is no value, that can be fixed during the process. The disadvantage of this way of computing new controller parameter values is that we do not know the current value of the Phase Margin or the Gain Margin.

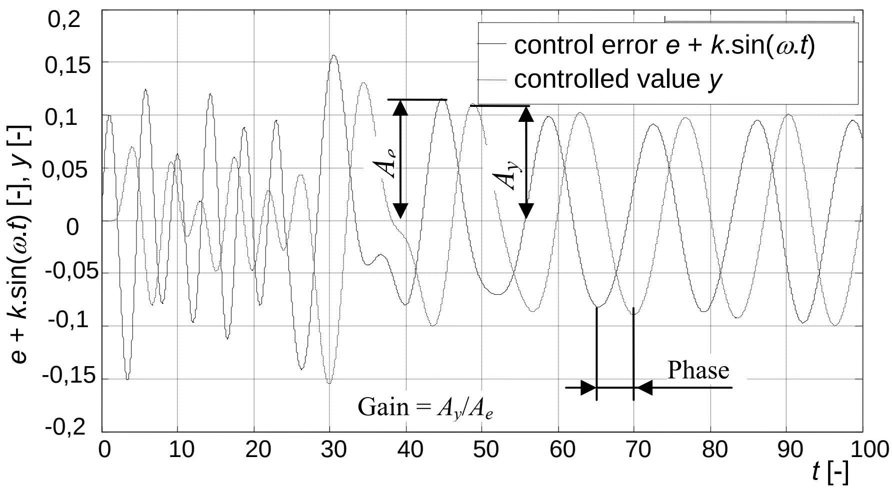

Figure 3 – Courses of control error and controlled value

The second way is that we find the current values of the indicators. Let us assume the Phase Margin evaluation again. The Phase margin should be equal to 60 degrees. Then we start to add harmonic signal $k.\sin(\omega.t)$ to control error e. The oscillation frequency ω makes the gain equal to one. Then we measure the current phase shift. If the phase shift is not equal to its desired value (in this case -120 degrees), the controller parameters are changed. Then we have to change the frequency of added oscillation ω to the gain stay equal to one, and measure the phase shift again. These actions are repeated until the measured phase is equal to -120 degrees. If the measured phase shift is equal to -120 degrees, the desired Phase Margin is found. We can use a similar procedure to Gain Margin evaluation and to Maximum Sensitivity evaluation too. The advantage of this way of computing new controller parameter values is knowledge of the current values of the evaluated indicators. The disadvantage is that this way takes more time than the first way, described above.

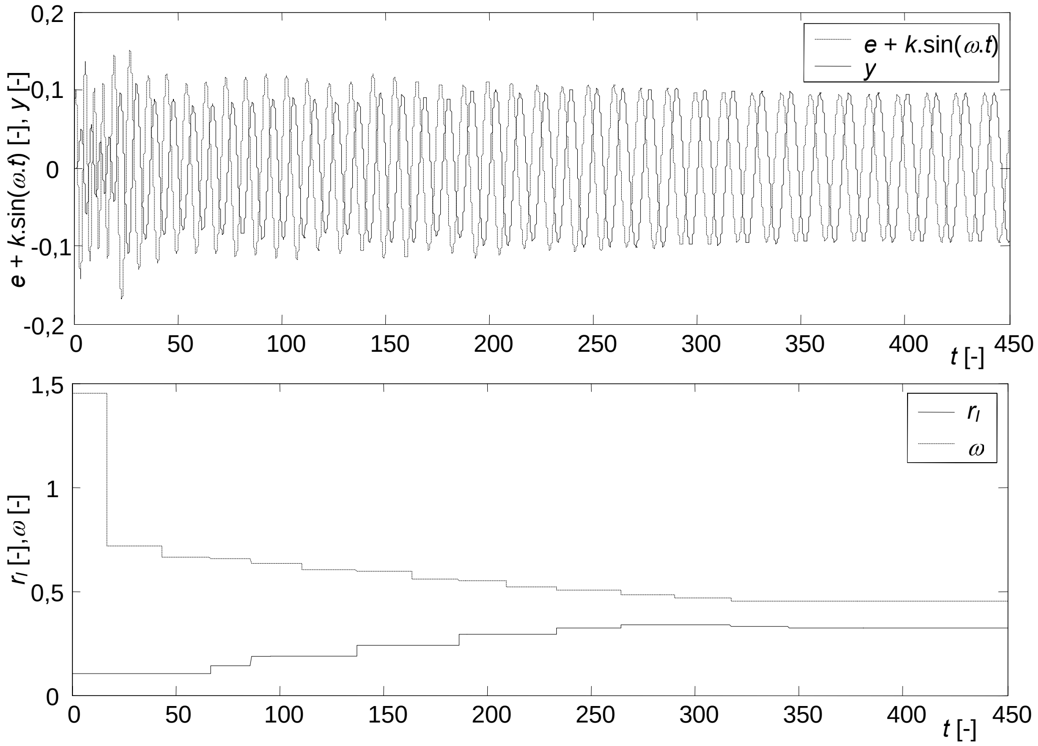

Figure 4 – Parameter changing

The course of control error with added harmonic signal $e + k.\sin(\omega.t)$ and the course of the controlled variable during indicator evaluation are depicted in the Figure 3. As is shown there, some artefacts can occur when the frequency is changed. When these artefacts are detected, they are eliminated from the subsequent signal processing. Changing the controller parameter along the frequency changing during controller tuning is depicted in the Figure 4. Only controller parameter r_I was allowed to be changed in the tuning mechanism. The other controller parameters stayed fixed at their original values (r_0 = 0,7, r_D = 0,1).

3 Conclusions

The method of autotuning presented here has a good chance to be implemented in industrial practice. It does not need any model of the controlled plant. While the controller is setting, the control function is not interrupted. The method needs more time for indicator evaluation than methods using step response evaluation. This is due to the need to wait when the amplitude of oscillation is steady after the frequency change.

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