LUND UNIVERSITY

The Idle Index

Hägglund, Tore

1997

Document Version:
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Hägglund, T. (1997). *The Idle Index*. (Technical Reports TFRT-7568). Department of Automatic Control, Lund Institute of Technology (LTH).

Total number of authors:
1

ISSN 0280–5316
ISRN LUTFD2/TFRT--7568--SE

The Idle Index

Tore Hägglund

Department of Automatic Control
Lund Institute of Technology
October 1997

Department of Automatic Control
Lund Institute of Technology
Box 118
S-221 00 Lund Sweden

Document name
INTERNAL REPORT

Date of issue
October 1997

Document Number
ISRN LUTFD2/TFRT--7568--SE

Author(s)
Tore Hägglund

Supervisor

Sponsoring organisation

Title and subtitle
The Idle Index

Abstract

This paper describes a procedure for automatic detection of sluggish control loops obtained from conservatively tuned controllers. A measure, the Idle index, of the sluggishness of the control loop is defined. The Idle index describes the relation between times of positive and negative correlation between the control and measurement signal increments. It can be determined with a very small amount of process knowledge, and is suitable for both on-line and off-line applications.

Key words

Classification system and/or index terms (if any)

Supplementary bibliographical information

ISSN and key title
0280–5316

ISBN

Language
English

Number of pages
11

Recipient's notes

Security classification

The report may be ordered from the Department of Automatic Control or borrowed through:
University Library 2, Box 3, S-221 00 Lund, Sweden
Fax +46 46 222 44 22 E-mail ub2@ub2.lu.se

The Idle Index

Tore Hägglund

Department of Automatic Control
Lund Institute of Technology
Box 118
S-221 00 Lund, Sweden
Phone: +46-46 2228798, Fax: +46-46 138118
Email: tore@control.lth.se

Abstract This paper describes a procedure for automatic detection of sluggish control loops obtained from conservatively tuned controllers. A measure, the Idle index, of the sluggishness of the control loop is defined. The Idle index describes the relation between times of positive and negative correlation between the control and measurement signal increments. It can be determined with a very small amount of process knowledge, and is suitable for both on-line and off-line applications.

Keywords Supervision, detection, diagnosis, performance.

1. Introduction

It is a sad and well-known fact, that most controllers in process control plants are poorly tuned. There are several reasons for this. A process control plant may include hundreds or thousands of control loops. To keep them properly tuned is normally considered too time consuming and often also too difficult. There is also a trend towards fewer operators that have to supervise larger sections of the process plants. This means that it becomes less likely that poor control loop performance will be discovered by operators. Furthermore, the control complexity has increased in recent years. For economical and environmental reasons, there is, e.g., a trend towards more recycling in the plants. This complicates the control problem.

On the other hand, there is an increasing understanding of the fact that badly tuned controllers causes losses in production as well as quality. See, e.g., Bialkowski (1993) and Ender (1993). Therefore, there is also a large industrial interest in supervisory functions that detect and make the operator aware of badly performing control loops. Some methods can be found in the area of fault detection, see Isermann (1984) and Frank (1990), although these methods mostly focus on more abrupt malfunctions.

There is also an increasing interest in off-line procedures and plant auditing. The Harris index, see Harris (1989) and Desborough and Harris (1992), has received lots of attention. In this method, the control loop performance is compared with an "optimal" performance, where optimal in this case means minimum-variance control. The Harris index and modifications of it have been applied in the pulp and paper industry, see e.g. Perrier and Roche (1992), Lynch and Dumont (1996), and Owen *et al.* (1996). It has also been applied in the chemical industry, see e.g. Stanfelj *et al.* (1993) and Thornhill *et al.* (1996). Conclusions about the control loop performance can also be deduced from spectral analysis. Examples are given in Desborough and Harris (1992) and Tyler and Morari (1996).

There are several reasons for bad control loop performance. One reason is stiction in the control valve, see Bialkowski (1993). This results in stick-slip motion and oscillations in the control loop. These oscillations can be detected by the method presented in Hägglund (1995) and Hägglund (1996).

Another important reason is unproper controller tuning. Most control loops in the process industry are conservatively tuned. This will not cause any oscillations or overshoots, but a conservatively tuned controller gives a sluggish response to load disturbances, and therefore unnecessary large and long deviations from the set point. This way of operating the process plants results in decreased product quality.

Why are the controllers conservatively tuned? The main reason is lack of time. The engineers tune the controllers until they are considered "good enough". They do not have the time to optimize the control. Many controllers are tuned once they are installed, and then never again. To retain stability when operating conditions change, the controllers are tuned for the "worst case". A better solution would of course be to use gain scheduling and perhaps adaptation. When a controller is retuned, it is mostly because the process conditions causes oscillatory control. In other words, when the controllers are retuned, they are detuned. When the process conditions change to sluggish control, the controller is normally not retuned again.

This paper describes a procedure to detect conservatively tuned controllers. A measure, the Idle index, of the sluggishness of the control loop is derived. The Idle index can be determined with a very small amount of process knowledge. It is suitable for both on-line and off-line applications.

2. The Idle index

Underlying idea

In process control, a controller is normally considered well tuned if it gives a fast response to load disturbances, but without any overshoot. Setpoint changes are not so important, unless the controller is a slave controller in a cascade configuration. Setpoint responses may be improved by other means than controller tuning, i.e. by feeding the setpoint through ramping modules or filters.

Figure 1 shows two responses to load disturbances in form of step changes at the process input. One response is good, with a quick recovery without any overshoot. The second response, however, is very sluggish. One feature that characterizes this second response is that there is a long

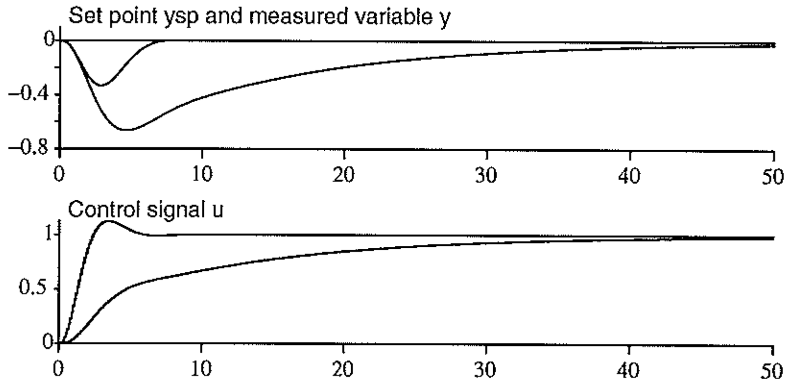

Figure 1 Good and bad control

period where both process output y and control signal u drift slowly in the same direction.

Both responses have an initial phase where the two signals go in opposite directions, i.e. $\Delta u \Delta y < 0$, where Δu and Δy are the increments of the two signals. What characterized the sluggish response is, that after this initial phase there is a very long time period where the correlation between the two signal increments is positive. This observation forms the base for the Idle index, which expresses the relation between the times of positive and negative correlation between the signal increments.

Definition of the Idle index

From now on, it is assumed that the sign of the static process gain is known, and for simplicity we assume that it is positive. Further, we assume that the control loop is subjected to load disturbances only. If there are setpoint changes present, these responses must be excluded from the analysis.

To form the Idle index, we first calculate the time periods when the correlations between the signal increments are positive and negative, respectively. The following procedures are updated every sampling instant

$$t_{\text{pos}} = \begin{cases} t_{\text{pos}} + h & \text{if } \Delta u \Delta y > 0 \\ t_{\text{pos}} & \text{if } \Delta u \Delta y \leq 0 \end{cases}$$

$$t_{\text{neg}} = \begin{cases} t_{\text{neg}} + h & \text{if } \Delta u \Delta y < 0 \\ t_{\text{neg}} & \text{if } \Delta u \Delta y \geq 0 \end{cases}$$

where h is the sampling period.

The idle index I_i is then defined by

$$I_i = \frac{t_{\text{pos}} - t_{\text{neg}}}{t_{\text{pos}} + t_{\text{neg}}} \tag{1}$$

Note that I_i is bounded to the interval $[-1, 1]$. A large positive value of I_i means that the control is sluggish. The Idle index for the sluggish response in Figure 1 is $I_i = 0.82$. A large negative value of I_i may be obtained in a well-tuned control loop. The Idle index for the good response in Figure 1 is $I_i = -0.63$. However, a large negative Idle index is also obtained in an oscillatory control loop. Therefore, it is desirable to combine the Idle index calculation with the oscillation detection procedure described in Hägglund (1995) in order to detect these systems. Idle indices close to zero indicates that the controller tuning is reasonably good. This is further discussed in Section 3.

Recursive calculations

At least for on-line applications, it is normally more convenient to calculate the Idle index recursively In this case, the following procedure is updated every sampling instant.

$$\begin{aligned}
&\text{if } \Delta u \Delta y > 0 \text{ then } s = 1\\
&\quad \text{else if } \Delta u \Delta y < 0 \text{ then } s = -1\\
&\quad \text{else } s = 0;\\
&\text{if } s \neq 0 \text{ then } I_i = \gamma I_i + (1-\gamma)s;
\end{aligned} \tag{2}$$

Here, factor γ determines the time horizon in the filter. In the off-line calculations, the signals are observed during a supervision time that is $T_{\text{sup}} = t_{\text{pos}} + t_{\text{neg}}$. This supervision time and the factor γ are related through

$$\gamma = 1 - \frac{h}{T_{\text{sup}}} \tag{3}$$

Filtering

The procedure is sensitive to noise, since we study the increments of the signals. It is therefore important to filter the signals. It is necessary to have some information about the process dynamics to find a suitable filter-time constant. In the on-line case, one can perhaps get this information from the controller parameters. The integral time in a PID controller should, e.g., give suitable information if it is properly tuned. In the off-line case one can use process identification.

It is also desirable to avoid calculations near steady-state, when the signal-to-noise ratio is small. A natural way to ensure this is to perform the calculations only when

$$|e| > e_0 \tag{4}$$

where e is the control error, and e_0 is a threshold based on a noise-level estimate or fixed to a few percent. This requires that the setpoint is available. This is no problem for on-line applications. For off-line applications one may be forced to estimate the setpoint from the process value signal.

Another approach is to identify the times of significant load disturbances, e.g. using the procedures given in Hägglund and Åström (1997). In this way, it is ensured that the Idle index is only based on periods with load disturbance transients. We automatically get rid of setpoint changes. These procedures also require some process knowledge.

Comparison with the correlation function

The correlation function between the two signals Δu and Δy is given by

$$\rho(\Delta u, \Delta y) = \frac{C(\Delta u, \Delta y)}{\sqrt{C(\Delta u, \Delta u)}\sqrt{C(\Delta y, \Delta y)}}$$

where the covariance functions are estimated according to

$$C(\Delta u, \Delta y) = \sum_{i=1}^{t} \Delta u(i) \Delta y(i)$$
$$C(\Delta u, \Delta u) = \sum_{i=1}^{t} \Delta u(i) \Delta u(i)$$
$$C(\Delta y, \Delta y) = \sum_{i=1}^{t} \Delta y(i) \Delta y(i)$$

An obvious approach would be to base the detection directly on the correlation function $\rho(\Delta u, \Delta y)$. The problem is, that the large magnitudes of Δu and Δy at the beginning of the transients will dominate in the calculation of $\rho(\Delta u, \Delta y)$, while we are interesting in the slow drifts at the end of the transients where the magnitudes of Δu and Δy are small. We do not want to take magnitudes of the increments into account.

The Idle index is identical to the correlation function

$$\rho(\text{sign}(\Delta u), \text{sign}(\Delta y))$$

i.e., the correlation function between the *signs* of the signal increments.

3. Examples

In this section, we will investigate the relation between the Idle index and load disturbance responses. Normally, the Idle index is supposed to be determined from a longer time-series analysis containing several disturbances. However, it is also possible to determine the Idle index from a single load disturbance response if it is combined with a load detection procedure as the one described in Hägglund and Åström (1997). Different applications of the Idle index are further discussed in Section 4.

In this section, load disturbance responses in form of a single step at the process input are treated. In the simulations, a process with the transfer function

$$G(s) = \frac{1}{(s+1)^3}$$

is controlled with a PID controller. The Idle index is calculated according to Equation (1). Although no noise is added in the simulations, the threshold defined in Equation (4) with $e_0 = 0.001$ is used.

All figures in this section are divided into three diagrams, where the upper one shows the setpoint and the process output, the middle one shows the control signal, and the lower diagram shows the sign of the correlation between Δu and Δy. This sign is set equal to zero when the control error is inside the bounds given by Equation (4).

Figure 2 shows the result when the process is controlled with a well-tuned PID controller. The controller is tuned according to the Kappa-Tau method described in Åström and Hägglund (1995). The controller parameters are, $K = 2.5$, $T_i = 2.2$, and $T_d = 0.56$. The response is fast without any overshoot. In this case we obtain an Idle index of $I_i = -0.68$. This large negative value indicates that we do not have any sluggish response.

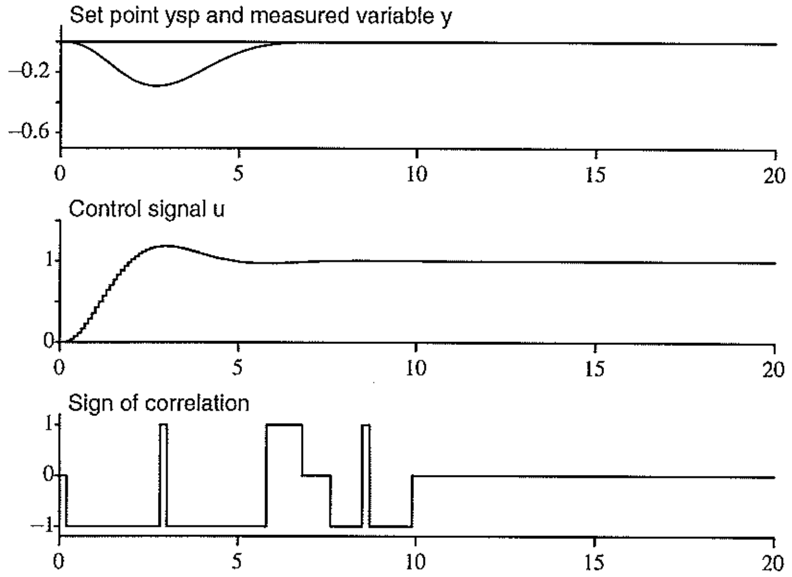

Figure 2 A well-tuned controller, tuned according to the Kappa-Tau method. The Idle index is $I_i = -0.68$.

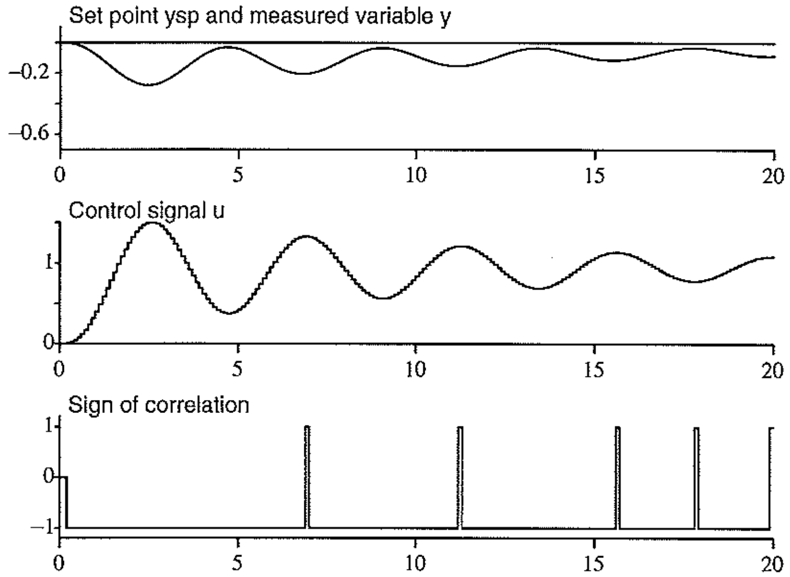

Figure 3 An oscillative load disturbance response. The Idle index is $I_i = -0.96$.

In Figure 3, the controller is tuned to give a very oscillative response. The controller is a PI controller with parameters $K = 5$ and $T_i = 15$. Since the two signals are oscillating with approximately −180° phase shift, we get an Idle index that is close to −1, namely $I_i = -0.96$. Due to the long integral time, we have a sluggish response, but it will not be detected by the Idle index method, since the oscillations dominate in the correlation calculations.

Figures 2 and 3 illustrate the difficulty in interpreting large negative values of I_i. Large negative values are obtained from both well behaved control loops and oscillatory loops. To distinguish between the two, an oscillation detection procedure as the one described in Hägglund (1995) and Hägglund (1996) can be used.

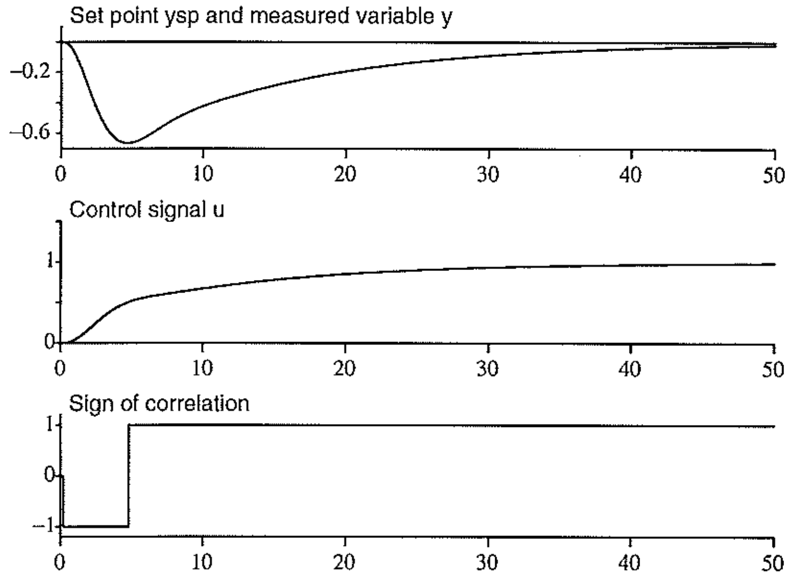

Figure 4 A sluggish load disturbance response. The Idle index is $I_i = 0.82$.

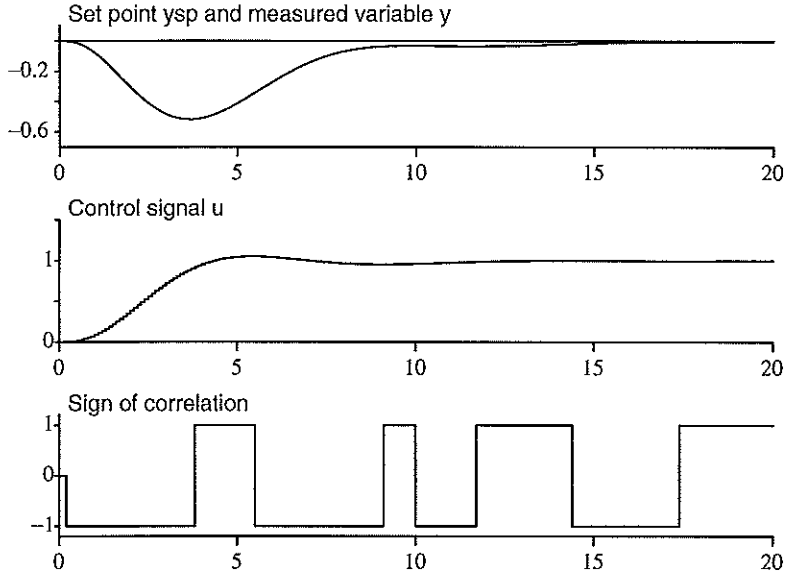

Figure 5 Load disturbance response resulting in $I_i = -0.21$.

Figure 4 shows a very sluggish response. It is obtained with the PI controller parameters $K = 0.5$ and $T_i = 5$. Notice that the figure shows a longer simulation than the previous ones. The correlation between the two signals is negative during the first transient, but then positive for a very long time. This results in the Idle index $I_i = 0.82$. The large positive value indicates that the control loop is sluggish.

The last two examples, presented in Figures 5 and 6, illustrate the limit for the detection procedure. Figure 5 shows control using the PI controller parameters $K = 1.0$ and $T_i = 2.5$. In Figure 6 the gain is decreased to $K = 0.7$, while we have the same integral time $T_i = 2.5$.

The responses obtained in the two examples are quite similar. The Idle indices differ, however, significantly. In Figure 5, the Idle index is $I_i = -0.21$ and in Figure 6, the Idle index is $I_i = 0.60$. The reason for this

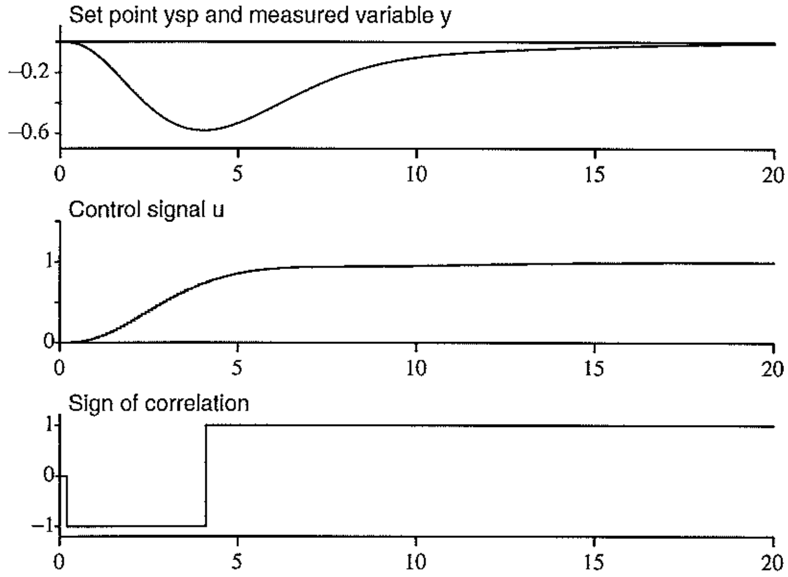

Figure 6 Load disturbance response resulting in $I_i = 0.60$.

difference is found in the control signal behaviour. In Figure 5 the control signal has an overshoot, resulting in periods of negative correlation even after the first transient. In Figure 6, however, the control signal decreases monotonously towards its stationary value. Therefore, we get a long period of positive correlation after the first transient.

These two last figures give an indication of the limits for the detection. Responses to step changes in load where the control signal has an overshoot are likely to be accepted, i.e. there will not be any large positive value of the Idle index. Responses where the control signal changes monotonously are likely to be detected, i.e. produce a large positive value of the Idle index.

Summary

The five examples presented in this section illustrate the properties of the Idle index. The results can be summarized as follows.

- Negative values of the Idle index are obtained from both well tuned control loops (Figures 2 and 5) and oscillatory control loops (Figure 3). Hence, we cannot draw any conclusions about the control performance from these values.
- Positive small Idle indices ($0 < I_i < 0.3$) indicate that the control loop is conservatively but well tuned.
- Large positive values of the Idle index indicate that the control loop is sluggish (Figures 4 and 6). These are the control loops that are supposed to be discovered by the Idle index methods.

4. Application areas

The Idle index can be used for both on-line and off-line detection of sluggish control loops. These two application areas will be discussed in this section.

On-line applications

The Idle index calculation can be implemented in the controllers or instrument systems for on-line supervision of the control loops. In this case, the calculations have to be performed recursively according to Equation (2).

In the on-line applications, there is some useful information available that is often lacking in off-line applications. Setpoint changes can easily be excluded from the calculations, since the setpoint is available in the control calculations. It is often also possible to find suitable filter time constants as well as the factor γ in Equation (3). They can be based on the integral- or derivative times of the PID controller. If the controller is tuned using some automatic tuning procedure, even more useful process information is available. See Åström and Hägglund (1995).

Off-line applications

The Idle index can also be used for off-line applications. Here, the calculations are normally performed in a system different from the instrument system that performs the control. This means, that we normally have less process information and process knowledge.

In some applications, it might happen that the only information available is the process output and control signal. On the other hand, lots of information can be obtained from these signals before one performs the calculation of the Idle Index. Suitable low-pass filters may be obtained from spectral analysis or process identification. It is also possible to determine sequences with setpoint variations from the two signals.

5. Industrial field tests

The usefulness of the new detection procedure has also been verified through industrial field tests. In this section we present results obtained from investigations performed on a heat exchanger. The control objective is to control the water temperature on the secondary side by controlling a water steam flow on the primary side.

Figure 7 shows load responses obtained with a conservatively tuned PI controller. The controller parameters were $K = 0.01$ and $T_i = 30s$. The signals are relatively noisy because of the low resolution, 1%, of the controller output. The control is sluggish. This is also well reflected by the Idle index that was calculated to $I_i = 0.8$.

The controller structure was changed to a PID controller and tuned properly resulting in the controller parameters $K = 0.025$, $T_i = 8s$, and $T_d = 2s$. The improved control behaviour is illustrated in Figure 8. The recovery after load disturbances is significantly faster, still without any noticeable overshoot. The improvements are also demonstrated by the Idle index that was reduced to $I_i = 0.3$.

6. Conclusions

In this paper we have presented a new procedure for detection of too conservatively tuned control loops. The procedure can be used for on-line as well as off-line applications. It requires only a limited amount of process

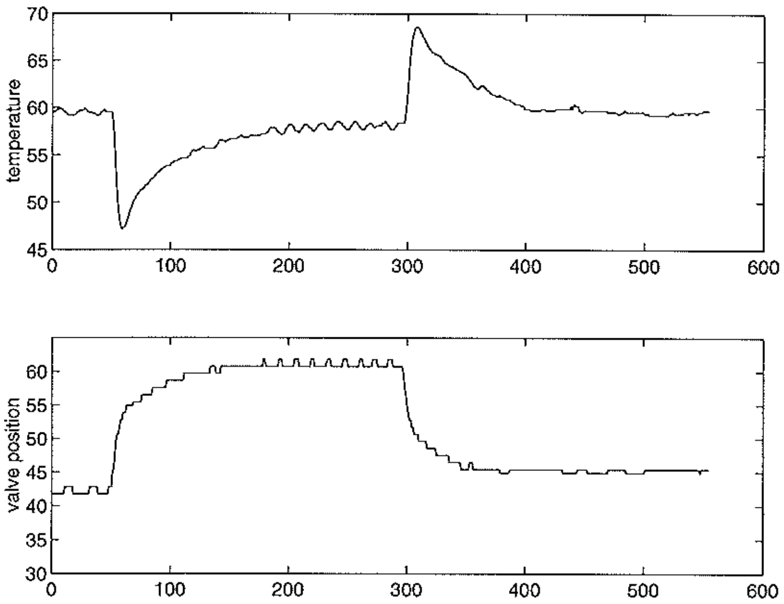

Figure 7 Temperature control with a conservatively tuned PI controller.

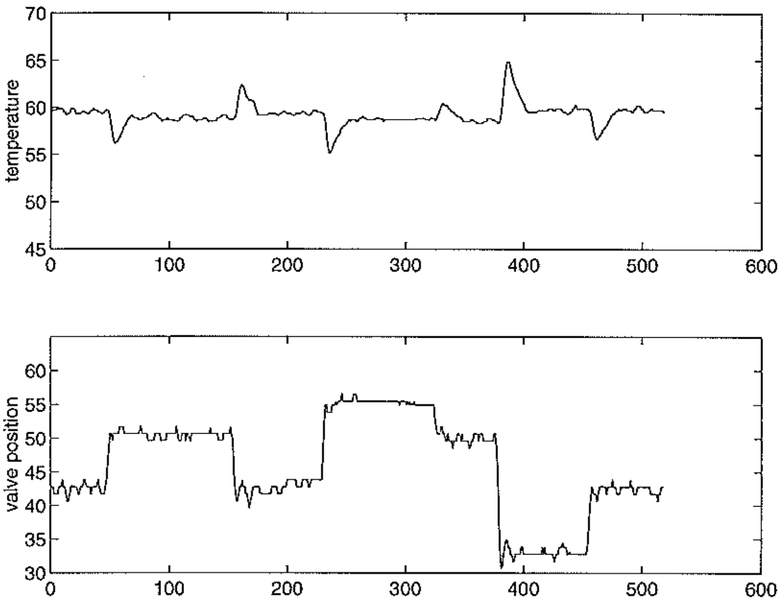

Figure 8 Temperature control with a properly tuned PID controller.

knowledge, and the calculations are few and simple. This is important especially for the on-line applications, where the intention is that the calculations should be made in parallel with the controller algorithm at each sample instant.

Simulation studies and industrial field tests have shown that the calculation of the Idle index forms a useful tool for diagnosing sluggish control loops. By discovering and retuning these loops, control loop performance and the quality of the process can be improved significantly in most process control plants.

7. References

ÅSTRÖM, K. J. and T. HÄGGLUND (1995): *PID Controllers: Theory, Design, and Tuning*, second edition. Instrument Society of America, Research Triangle Park, NC.

BIALKOWSKI, W. L. (1993): "Dreams versus reality: A view from both sides of the gap." *Pulp and Paper Canada*, **94:11**.

DESBOROUGH, L. and T. HARRIS (1992): "Performance assessment measures for univariate feedback control." *Can. J. Chem. Eng.*, **70**, pp. 1186–1197.

ENDER, D. B. (1993): "Process control performance: Not as good as you think." *Control Engineering*, **40:10**, pp. 180–190.

FRANK, P. M. (1990): "Fault diagnosis in dynamic systems using analytical and knowledge-based redundancy—A survey and some new results." *Automatica*, **26:3**, pp. 459–474.

HÄGGLUND, T. (1995): "A control-loop performance monitor." *Control Engineering Practice*, **3**, pp. 1543–1551.

HÄGGLUND, T. (1996): "Modern controllers supervise valves automatically." *InTech*, **43:1**, pp. 44–46.

HÄGGLUND, T. and K. J. ÅSTRÖM (1997): "Supervision of adaptive control algorithms." In *IFAC conference on control of industrial systems*. Belfort, France.

HARRIS, T. J. (1989): "Assessment of control loop performance." *Can. J. Chem. Eng.*, **67**, pp. 856–861.

ISERMANN, R. (1984): "Process fault detection based on modeling and estimation methods—A survey." *Automatica*, **20**, pp. 387–404.

LYNCH, C. B. and G. A. DUMONT (1996): "Control loop performance monitoring." *IEEE Trans. Control Syst. Technol.*, **4**, pp. 185–192.

OWEN, J. G., D. READ, H. BLEKKENHORST, and A. A. ROCHE (1996): "A mill prototype for automatic monitoring of control loop performance." In *Proc. Control Syst. '96*. Halifax, Nova Scotia, Canada.

PERRIER, M. and A. A. ROCHE (1992): "Towards mill-wide evaluation of control loop performance." In *Proc. Control Syst. '92*. Whistler, B.C.

STANFELJ, N., T. MARLIN, and J. MACGREGOR (1993): "Monitoring and diagnosing process control performance: The single-loop case." *Ind. Eng. Chem. Res.*, **32**, pp. 301–314.

THORNHILL, N. F., R. SADOWSKI, J. R. DAVIS, P. FEDENCZUK, M. J. KNIGHT, P. PRICHARD, and D. ROTHENBERG (1996): "Practical experiences in refinery control loop performance assessment." *IEE Conference Publication*, **427/1**, pp. 175–180.

TYLER, M. L. and M. MORARI (1996): "Performance monitoring of control systems using likelihood methods." *Automatica*, **32**, pp. 1145–1162.