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Setpoint Versus Disturbance Responses of the IPDT Plant

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Abstract: This paper considers PI controller tuning for Integral Plus Dead Time plant (IPDT) by new Matlab/Simulink tool based on the performance portrait method. It enables to guarantee transient responses with specified deviations from ideal shapes at the plant output and input and to fulfill additional optimality specification, defined in terms of the minimal IAE (Integral of Absolute Error) values weighted for the setpoint and disturbance steps. As the ideal step responses at the plant output monotonic transients are considered, whereas at the plant input one-pulse responses consisting of two monotonic intervals are required. As an introduction to new generation of robust tuning approaches, optimal nominal tuning is firstly treated.

Keywords: Proportional-integral control, optimal control, robust control, dead time.

1. INTRODUCTION

Tuning of the PI controller for IPDT plant with the gain K_s and dead time Td

$$F(s) = \frac{K_s}{s} e^{-T_d s} \tag{1}$$

is frequently treated in all control areas. In connection with appropriate model reduction techniques it enables to approximate broad range of processes Åström and Hägglund (2005), Skogestad (2003). Consequently, high number of different "optimal" tuning rules based on this model may be found in the literature O'Dwyer (2009).

When considering tuning rules appropriate for education & practice, it is to agree with Skogestad (2003) that they should be 1. well motivated, 2. preferably model-based, 3. analytically derived, 4. simple and easy to memorize and 5. work well on a wide range of processes. When continuing with requirements of Skogestad (2006), controller tuning should enable trade-off between: fast speed of response, good disturbance rejection, stability & robustness, less input usage and less sensitivity to measurement noise.

The analytical methods for controller tuning (see e.g. Oldenbourg and Sartorius (1944,1951)) were used from the early beginning of the PID control. But, simultaneously with them, also the experimental controller tuning played always an important role, what may be demonstrated by high popularity of the early tuning by Ziegler and Nichols (1942) that still gives inspiration for many new approaches Åström and Hägglund (2004), Hägglund and Aström (2002). Of course, except of the analytical design, main requirements on such tuning remain mostly the same.

In this paper we are going to show how the trade-off between high speed of the setpoint tracking and good disturbance rejection may be balanced under requirements of robust control with performance specified by the minimal IAE values and by tolerable deviations from ideal shapes at the plant input and output for any loop parameters in (1). This is enabled by the new method of the Performance Portrait (PP) Huba (2010), Huba (2011) that is based on carrying out series of simulation experiments on some sample of representative processes. The method gives very promising results especially when dealing with dead time systems, for which there is free space for improving the up to now existing methods already in nominal control. It will be shown that the design based exclusively on the setpoint response may lead to useless results and when wishing to solve the problem as simply as possible, the disturbance response represents the more useful alternative. However, as the best solution, a balanced controller tuning considering simultaneously both responses taken with appropriate weights is shown.

The paper is structured as follows. In Chapter 2 several traditional tuning methods are discussed to characterize their basic properties and to enable their comparison with the newly proposed method. In Chapter 3, basic requirements on robust controller tuning are summarized and performance measures for robust controller tuning in the time domain are introduced. In Chapter 4 the performance portrait for plant (1) is described and then used in Chapter 5 for optimal tuning based on minimization of weighted IAE values of setpoint and disturbance step responses subject to shape related constraints for the plant input and output. The achieved results are compared with those corresponding to the first-generation robust tuning methods. Basic conclusions are summarized in Chapter 6.

2. FIRST GENERATION OF ROBUST CONTROLLER TUNING METHODS

Next we will briefly introduce several analytical and numerical robust tuning methods that may be used in a comparative analysis for the IPDT plant.

2.1 Analytical controller design - TRDP

Based on generalization of the double real dominant closed loop pole Oldenbourg and Sartorius (1944,1951) to triple real dominant pole (TRDP), whereby the PI controller is extended by the setpoint weighting b according to

$$U(s) = K_c\left[bW(s) - Y(s)\right] + \frac{K_c}{sT_i}\left[W(s) - Y(s)\right] \quad (2)$$

with T_i being the integral time constant, or by the equivalent prefilter

$$F_p(s) = \frac{bT_is + 1}{T_is + 1} \quad (3)$$

an interesting nominal tuning was analytically derived both for regulatory as well as tracking control tasks in Vítečeková and Víteček (2008). Existence of a triple closed loop pole s_0 requires to fulfill

$$A(s_0) = 0 \ ; \ \dot{A}(s_0) = 0 \ ; \ \ddot{A}(s_0) = 0 \quad (4)$$

$$\begin{aligned} A(s) &= s^2T_ie^{T_ds} + K_rK_s(T_is + 1) \\ \dot{A}(s) &= 2sT_ie^{T_ds} + s^2T_dT_ie^{T_ds} + K_rK_sT_i \\ \ddot{A}(s) &= 2T_ie^{T_ds} + 4sT_dT_ie^{T_ds} + s^2T_d^2T_ie^{T_ds} \end{aligned} \quad (5)$$

Solution of $\ddot{A}(s_0) = 0$ yields root

$$s_0 = -(2 - \sqrt{2})/T_d \quad (6)$$

From the first two equations in (4) one gets stable tuning

$$\begin{aligned} K_c &= 2(\sqrt{2} - 1)e^{\sqrt{2}-2}/(K_sT_d) \approx 0.461/(K_sT_d) \\ T_i &= (2\sqrt{2} + 3)T_d \approx 5.828T_d \end{aligned} \quad (7)$$

Zero of the closed loop transfer function

$$F_{wy} = \frac{K_sK_c(T_is + 1)}{T_is^2e^{T_ds} + K_sK_c(T_is + 1)} \quad (8)$$

can be canceled by the prefilter denominator in (3) that removes overshooting typical for the one-degree-of-freedom PI controllers. Simultaneously, by canceling one of the triple pole (6) by the prefilter numerator (3) to accelerate transient responses, one gets setpoint weighting

$$b = \frac{1/|s_0|}{T_i} = \frac{2 - \sqrt{2}}{2} \approx 0.293 \quad (9)$$

The corresponding maximal sensitivity and the complementary sensitivity peaks are $M_s = 1.70; M_t = 1.44$. Achieved transients compared with other tuning approaches are given in Figs. 2-3. Basic advantage of this tuning is given by compactness and elegance of its derivation: it gives fast and smooth responses both in regulatory as well as tracking control.

2.2 SIMC PI Controller

As the 2nd example, the analytical controller tuning known as the SIMC PI-rule (abbreviation from Simple/Skogestad Internal Model Control) for fast response with good robustness Skogestad (2003) will be mentioned.

Firstly, by considering direct controller synthesis Rivera et al. (1986), Skogestad (2003) leading for a general first order plus dead time (FOPDT) plant

$$F_s = \frac{K_se^{-T_ds}}{s + 1/T_1} \quad (10)$$

to a simple first-order setpoint-to-output closed loop transfer function with time constant τ_c

$$F_{wy} = \frac{R(s)F(s)}{1 + R(s)F(s)} = \frac{R(s)K_s}{(s + 1/T_1)e^{T_ds} + R(s)K_s} \quad (11)$$

$$F_{wy} \stackrel{!}{=} \frac{1}{1 + \tau_cs}e^{-T_ds} \quad (12)$$

the PI controller

$$R(s) = \frac{s + 1/T_1}{K_s(\tau_c + T_d)s} \quad (13)$$

is derived, whereby the exponential term may be eliminated by using its first-order Taylor series approximation

$$e^{-T_ds} \approx 1 - T_ds \quad (14)$$

what requires to use $\tau_c \geq T_d$. For stable 1st order systems usually $T_i = T_1$ and $K_c = 1/(K_sT_1(\tau_c+T_d))$. However, for integral systems, when $T_1 \to \infty$, solution (13) is actually approaching the proportional controller, what leads to poor rejection of input (load) disturbances. Of course, it is still possible to choose PI controller and to look for its appropriate tuning by other means, but then it is no more the above mentioned direct controller synthesis of the IMC control. So, the question arises if the abbreviation SIMC is still appropriate for integral plants. In Skogestad (2003) tuning for such systems is derived by analyzing conditions of the critically damped closed loop system with the PI controller and integral delay-free plant ($T_d = 0$), when the double real dominant pole may be achieved by choosing

$$T_i = 4/(K_sK_c) \quad (15)$$

Finally, to consider dead time, the closed loop time constant in (12) was chosen as $\tau_c = T_d$ what yields

$$K_c = 1/(2K_sT_d) \ ; \ T_i = 8T_d \quad (16)$$

This tuning may be considered as simplification of the above method (double real dominant pole instead of the triple one). It is simple, easy to remember and in comparing with the traditional IMC tuning rules and other tested methods (see Figs. 2-3) it brings a reasonable improvement of the input-disturbance response with moderate input usage and good robustness margins both in regulatory as well as tracking control. The analytical controller derivation is no more as compact as in the above case. Tuning of the integral part was made for delay-free system what leads to a question, in which range of the dead-time values it will keep the expected performance. On the other hand, together with the "half-rule" enabling to deal effectively with more complex plants by possibly simple means.

When comparing integral loops with controller (16) with the IMC control of stable plants, it is also to note that for the integral plant the output setpoint step responses typically have overshooting, whereas in controlling stable 1st order plants (10) the closed loop step responses (12) are monotonic both at the plant input and output. In controlling integral plants, monotonic setpoint step responses at the plant output are possible just with the setpoint weighting (2-3). However, since the method does not give information about the dominant closed loop poles, a setpoint weighting guaranteeing purely monotonic output can be determined just experimentally as

$$b = 0.592 \quad (17)$$

By using specifications in the frequency domain, it was shown that for integrating processes tuning (16) it gives the gain margin $GM = 2.96$, the phase margin $PM = 46.9°$, the maximal and the complementary sensitivity peaks $M_s = 1.70; M_t = 1.30$, and the maximum allowed time delay error with respect to stability is $1.59T_d$.

2.3 Optimization Based PI Control with $max\{K_i\}$

As the 3rd approach to be compared with the new tuning the numerical non-convex optimization method Åström et al. (1998) is mentioned. Based on the frequency-domain loop specifications by the maximum and complementary sensitivity peaks $M_s = 1.40$ and $M_t = 1.45$ it gives

$$b = 0.66; K_c = 0.282/(K_sT_d)$$
$$K_i = \frac{K_c}{T_i} = \frac{0.0418}{K_sT_d^2} \Rightarrow T_i = 6.746T_d \quad (18)$$

The optimization problem was specified as follows: find controller parameters that maximize the integral gain $K_i = K_c/T_i$ subject to the constraints that the closed-loop system is stable, the Nyquist curve of the loop transfer function satisfies the encirclement condition and that it is outside a circle that has the M_s and M_t circles in its interiors. Although it might seem that standard optimization routines are sufficient to solve this problem, it was shown that *"the optimization problem is nontrivial, the parameter space is not convex"*. The found tuning yields IAE values (Figs. 2-3) that are much larger than those corresponding to other tested approaches: they do not allow achieving monotonic output setpoint step response even for $b = 0$.

Obviously being aware of too conservative tuning (18), in Hägglund and Aström (2002) new tuning rules were published based on Approximative M_s-constrained Integral Gain Optimization (AMIGO). These results corresponds to the maximum and complementary sensitivity peaks $M_s = 1.48$ and $M_t = 1.39$. Extended by the choice $b = 0$

$$b = 0\ ;\ \ K_c = 0.35/(K_sT_d)\ ;\ \ T_i = 7T_d \quad (19)$$

they will be used to achieve nearly monotonic setpoint and disturbance step responses (Figs. 2-3).

2.4 Tuning by Mataušek and Šekara (2011) with $max\{K_c\}$

The last considered controller tuning with parameters

$$b = 0\ ;\ \ K_c = 0.9037/(K_sT_d)\ ;\ \ T_i = 5.0122T_d \quad (20)$$

$M_s = 1.73$ and $M_t = 1.54$ was calculated by transformations of a small amount of measured process characteristics (ultimate frequency and gain, angle of the tangent to the Nyquist curve at the ultimate frequency and the static gain). Practically the same performance/robustness tradeoff was obtained by applying controller optimization requiring maximal K_c gain. In comparing with the non-convex optimization it reasonably improves IAE values for the disturbance response, whereas it guarantees critically damped load disturbance and setpoint step responses for a large class of stable, integrating and unstable processes.

3. SHAPE RELATED PERFORMANCE MEASURES

All tested methods are working with M_s values from a relatively narrow range 1.4-1.73, but despite to this their robustness and performance reasonably differ. So, flexibility of the non-convex optimization in Åström et al. (1998) based on the choice of the maximal sensitivity M_s is far from the originally proclaimed aims *"... to have a design parameter to change the properties of the closed-loop system. Ideally, the parameter should be directly related to the performance of the system, it should not be process oriented. There should be good default values so a user is not forced to select some value... The design parameter should also have a good physical interpretation and natural limits to simplify its adjustment."* Furthermore, all above methods do not really include a free parameter for balancing dynamics of the setpoint and disturbance responses. Therefore, next we are going to look for more appropriate method enabling to fulfill aims of robust performance without leading to unnecessarily conservative tuning.

From the performance point of view, at the plant output the expected dynamics is frequently specified in form of *monotonic (MO)* setpoint step responses. Ideal continuous signal at the plant input giving after integration by the plant dynamics MO output will be denoted as the *one-pulse (1P) control*. It may be characterized as a pulse with one extreme point, or saturating interval separating two MO increasing and decreasing (or vice versa) intervals.

Having in mind these two shape related performance requirements, it is to note that they are not sufficiently captured by traditional performance measures like gain margin, phase margin, maximum sensitivity, H_∞ norm, etc. MO control together with a performance index for its evaluation was e.g. mentioned in Åström and Hägglund (2004), Hägglund and Aström (2002). One of recent reviews on PID control Keel et al. (2008) is mentioning just output non-overshooting control. Application of the corresponding performance design in the frequency domain is extremely complicated, especially when speaking about dead time systems. For evaluating control effort needed to achieve required output behavior, Total Variance (TV) was proposed Skogestad (2003) as

$$TV = \int_0^\infty \left|\frac{du}{dt}\right| dt \approx \sum_i |u_{i+1} - u_i| \quad (21)$$

Typically, its values are computed after discretization with sampling period as small as possible, what in Matlab may be simply computed by the command `sum(abs(diff(u))`.

Based on TV, new measures for deviations from MO and 1P shapes will be preferred Huba (2010 2011) that may be easily tested numerically by evaluating simulated or experimentally measured setpoint and disturbance step responses and are also appropriate for constrained control. For evaluating deviations from strictly MO plant output $y(t)$ with the initial value y_0 and the final value y_∞ the $TV_0(y)$ measure is proposed as

$$TV_0(y) = \sum_i |y_{i+1} - y_i| - |y_\infty - y_0| \quad (22)$$

$TV_0(y) = 0$ just for strictly MO response, else $TV_0(y) > 0$.

In controlling unstable and integral plants the number of significant control pulses cannot decrease below the number of unstable poles Huba (2009), Huba (2010). To stress contribution of the superimposed oscillation in systems with 1P dominant control it is then appropriate to work with the TV_1 criterion defined for $u_m = max\{u(t)\}$ as

$$TV_1(u) = \sum_i |u_{i+1} - u_i| - |2u_m - u_\infty - u_0| \qquad (23)$$

$TV_1(u) = 0$ just for strictly 1P response, else for control signals with superimposed higher harmonics $TV_1(u) > 0$.

4. CLOSED LOOP PERFORMANCE PORTRAIT (PP)

Because of lacking analytical tools, the controller will be robustly tuned by using numerically derived areas of parameters corresponding to the above mentioned shape-related properties. The aim is to expand nice dynamics of the nominal case given e.g. by the tuning (7-9) fulfilling requirements on ideal shapes both at the plant input and output to plant with parameters known over uncertainty intervals Huba (2009), Huba (2010), Huba (2011).

The closed loop PP represents information about the loop performance corresponding to the setpoint and the disturbance step responses evaluated over a grid of (possibly normalized) loop parameters. This information may be visualized and used both for optimally choosing nominal controller for a completely known plant, or for robust controller tuning of a plant with interval parameters. This new approach may be understood as generalization of the parameter space method Ackermann (2002). For a loop represented by a parameter vector

$$P = \{p_1, p_2, \dots p_S, p_{S+1}, p_{S+I}\} \qquad (24)$$

with the dimension

$$D = S + I \qquad (25)$$

each entry $p_i; i = 1, \dots, S$ of the first subset of parameters represents a value that has to be fixed during the controller tuning. Possibly uncertain (plant) parameters

$$p_i \in \langle p_{imin}, p_{imax}\rangle\,; \qquad i = S+1, \dots, S+I \qquad (26)$$

that vary over some (known) intervals may be represented by discrete $n_i + 1$ working points

$$\begin{aligned} p_{i,j} &= p_{imin} + (p_{imax} - p_{imin})j/n_i; \\ j &= 1, 2, \dots, n_i; n_i > 1; i = S+1, \dots, S+I \end{aligned} \qquad (27)$$

The controller tuning has to be specified in such a way that for a set P an optimal mean value of the chosen performance measure is achieved, whereby the shape-related performance specifications are kept. When working with the plant (1), the controller (2-3) is specified by three parameters b, K_c, T_i. The task may be formulated as:

a) to find controller parameters b, K_c, T_i guaranteeing for given K_s, T_d optimal performance $min\{mean\{IAE_w\}\}$, or

b) for controllers defined e.g. by formulas of Chapter 2 to find an appropriate operating point K_{s0}, T_{d0}.

The necessary amount of computation and the achieved precision depend on the level of quantization and on the choice of the possible preliminary limits of the free parameters that have to be determined. Thereby, one has to balance precision of achieved results (quantization level in considered grid) with the total number of evaluated points and the corresponding computation time.

5. COMPARATIVE ANALYSIS OF PI TUNINGS

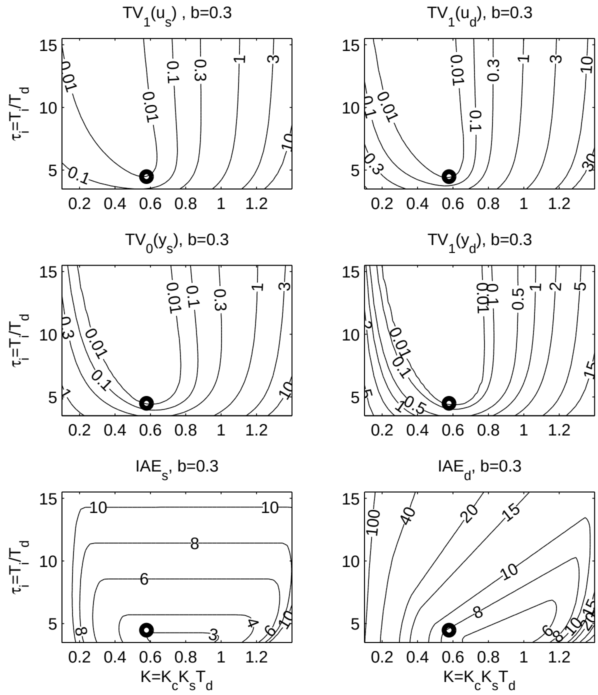

Fig. 1. One layer of the PP ($b = 0.3$) calculated for the setpoint step responses over 50x50x21 points and containing the optimal nominal tuning corresponding to min IAE_w with $w_s = 0.5$ - note similarities between both $TV_1(u)$ and $TV_0(y_s) - TV_1(y_d)$ portraits for the setpoint and disturbance responses; $\epsilon = 0.011$

For quantitative evaluation of the speed of responses the IAE (Integral of Absolute Error) will be used defined as

$$IAE = \int_0^\infty |e(t)|\, dt\ ;\ \ e = w - y \qquad (28)$$

Tuning guaranteeing under shape related constraints the minimal possible IAE_s values for the setpoint step response was analyzed in Huba (2011). It leads to controller with $K_i = K_c/T_i \rightarrow 0$ that is not able to eliminate disturbances. One possibility to avoid this handicap is to look for tuning satisfying $max\{K_i\}$ Åström et al. (1998), or $max\{K_c\}$ Mataušek and Šekara (2011). A more direct strategy is to find controller parameters b, K_c, T_i guaranteeing for given plant parameters K_s and T_d $min\{IAE_w\}$

$$\begin{aligned} &IAE_w = w_s IAE_s/IAE_{s,min} + w_d IAE_d/IAE_{d,min} \\ &w_s + w_d = 1\ ;\ \ w_s \in \langle 0,\, 1\rangle \end{aligned} \qquad (29)$$

whereby w_s and w_d are the weighting coefficients and $IAE_{s,min}$, or $IAE_{d,min}$ represent IAE_s and IAE_d values achieved by separate optimization of setpoint and disturbance responses under chosen shape related constraints.

Fig. 1 shows several windows of one layer of the 3D PP calculated for the setpoint and disturbance steps over 50x50x21 points with normalized parameters $K = K_cK_sT_d \in \langle 0.1, 1.4\rangle\,;\ \tau_i = T_i/T_d \in \langle 3.5, 15.5\rangle\,;\ b \in \langle 0, 1\rangle$

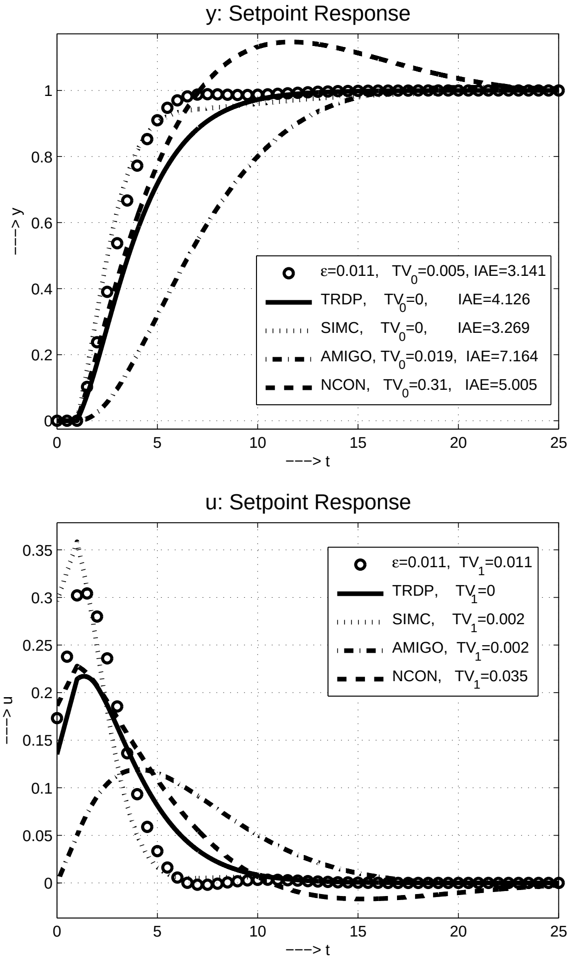

Fig. 2. Setpoint step responses at the plant output and input corresponding to the optimal tuning according to Fig. 1 (red) compared with TRDP (7-9), SIMC (16) and non-convex optimization (18-19); $Ks = 1$; $T_d = 1$

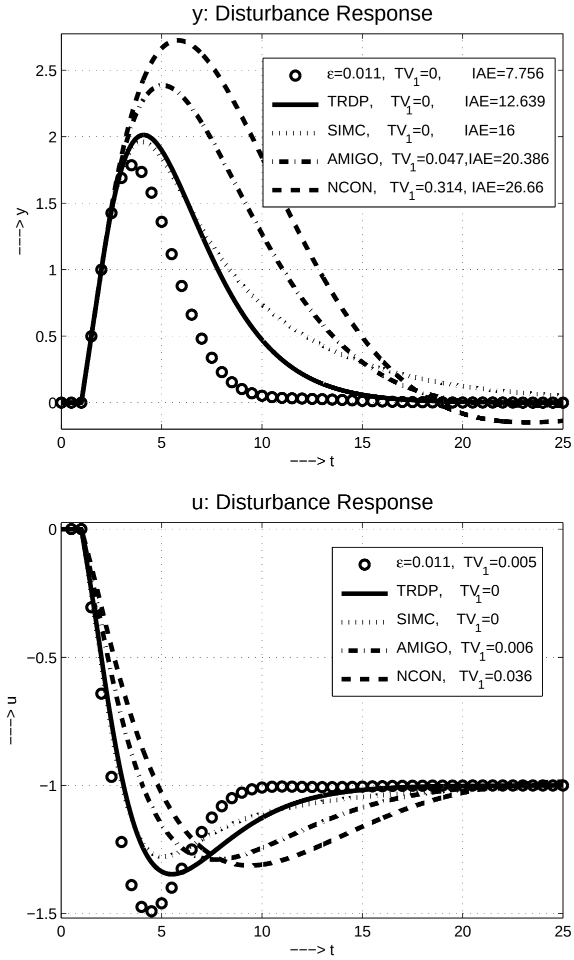

Fig. 3. Load-disturbance step responses at the plant output and input corresponding to the optimal tuning according to Fig. 1 (red) compared with TRDP (7-9), SIMC (16) and non-convex optimization (18-19).

for $\epsilon = \epsilon_y = \epsilon_u = 0.011$. Once having PP generated for normalized parameters, it may be repeatedly used for different tasks with different loop parameters. For $w_s = 0.5$ the optimal operating point gives the minimal IAE_w value with tolerable integral deviations from MO/1P output (setpoint/disturbance responses) and 1P input

$$\begin{array}{l} TV_0(y_s) \le \epsilon_{ys} \; ; \; TV_1(y_s) \le \epsilon_{yd} \\ TV_1(u_s) \le \epsilon_{us} \; ; \; TV_1(u_d) \le \epsilon_{ud} \end{array} \tag{30}$$

These conditions mean that the potential overshooting of the nearly MO setpoint response, or the second possible pulse of nearly 1P control have amplitudes less than given by the particular value of $\epsilon/2$.

Although the setpoint and disturbance responses in Fig. 2 and Fig. 3 corresponding to the controller parameters

$$K_c = 0.5776/(K_s T_d) \; ; \; T_i = 4.4796 T_d \; ; \; b = 0.3 \tag{31}$$

do not necessarily represent an absolute optimum, achieved IAE values are reasonably better than those corresponding to all above mentioned controllers. The setpoint response characterized by $IAE_s = 3.14 T_d^2$ is by nearly 4% better than the best setpoint response proposed by modification of Skogestad (2003), but the disturbance response value $IAE_d = 7.76 T_d^2$ is already by 106% better than the solution by Skogestad (2003) and by 63% better than the solution by Vítečková and Víteček (2008). By increasing ϵ_y and ϵ_u, or by decreasing the quantization step the identified solutions might yet be improved. E.g. PP generated for 51x51x65 points over a narrower range $K \in \langle 0.55, 0.65\rangle$; $\tau_i \in \langle 4.3, 6.8\rangle$; $b \in \langle 0, 0.64\rangle$, $w_s = 0.5$ width $\epsilon_y = \epsilon_u = 0.033$ corresponding to $TV_0(y)$ of the controller by Mataušek and Šekara (2011) yields

$$K_c = 0.6140/(K_s T_d) \; ; \; T_i = 4.3000 T_d \; ; \; b = 0.31 \tag{32}$$

$IAE_s = 2.972 T_d^2, TV_0(y_s) = 0.028 T_d, TV_1(u_s) = 0.032$ and $IAE_d = 7.003 T_d^2, TV_1(y_d) = 0.008 T_d, TV_1(u_d) = 0.031$. This possibility to reasonably improve loop properties gives the best explanation for inflation of optimal solutions documented by O'Dwyer (2009). The new method finally satisfies needs on reliable controller tuning enabling to match practical requirements by choice of four parameters $\epsilon_{ys}, \epsilon_{yd}, \epsilon_{us}, \epsilon_{ud}$ with clear control interpretation.

Fig.4 shows dependences of optimal IAE_s values normed by the $IAE_{s,min}$ and IAE_d normed by the $IAE_{d,min}$ on w_s. For $w_s \to 1$ IAE_d values rapidly increase, what explains, why controller tuning based on the disturbance responses is usually considered. Since near $w_s = 0$ also IAE_s values increase, choice $w_s = 0.5$ may be recommended

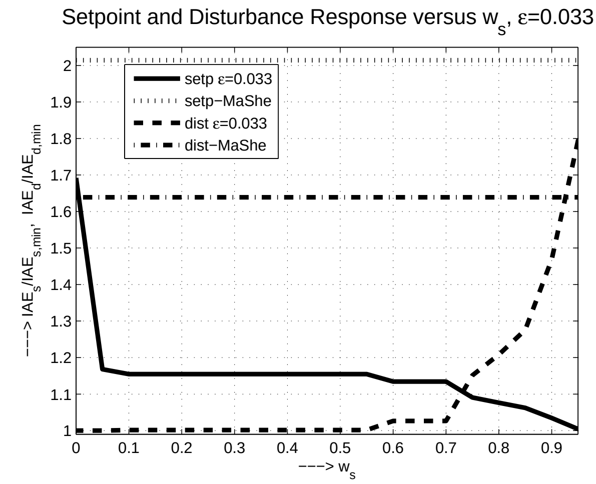

Fig. 4. Normalized IAE_s and IAE_d values versus w_s calculated from PP generated for 51x51x65 points; $K \in \langle 0.55, 0.65 \rangle$; $\tau_i \in \langle 4.3, 6.8 \rangle$; $b \in \langle 0, 0.64 \rangle$; $\epsilon_y = \epsilon_u = 0.033$ corresponding to $TV_0(y_s)$ of the controller by Mataušek and Šekara (2011) denoted by "MaShe"

for practical use. Whereas IAE_d values increase, IAE_s values decrease and vice-versa, i.e. good PI controller has slower setpoint response than the P one. This may be avoided by using disturbance observer based PI controllers enabling moreover to freely enhance filtering properties and to exclude windup in constrained control Huba (2012).

Fig.4 allows also comparison with the controller by Mataušek and Šekara (2011). Its normed IAE_s and IAE_d values that do not depend on w_s are given by horizontal lines lying more than 2, or 1.6 times over the minimal IAE values of the performance portrait based tuning.

6. CONCLUSIONS

New performance portrait based method was illustrated by the frequently treated task of the PI controller tuning for the IPDT plant. For the first time, different requirements on the setpoint and disturbance response may flexibly be taken into account by specifying weights w_s and $w_d = 1 - w_s$ of both responses, as well as by specifying four shape related tolerable deviations from ideal monotonic and one-pulse transients at the plant output and input.

The carried out comparative analysis including several types of the first-generation robust tuning approaches for the IPDT plant has shown their typical features: in some context they may give excellent properties, but they are not flexible enough to cope with variety of practical requirements. In this sense the new approach showed to be much more effective and efficient. The traditional methods are typical by a preprogrammed and so possibly unnecessarily high reserve of the nominal tuning and they do not really allow to balance dynamics of both considered responses. The new method directly gives solution optimally fitting the specified performance measures without any redundant precaution. Analysis of the nominal tuning is aimed as introduction to design with plant specified over uncertainty intervals Huba (2011).

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