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ACTIVE DIAGNOSIS OF SELF-TUNING PID CONTROL SYSTEMS BASED ON ANALYSIS OF INTERNAL PHENOMENA WITHIN THE CONTROLLERS - SELECTED APPLICATIONS -

Key words: PID algorithm, control system, self-tuning, internal phenomena, verification

Abstract: Most of the phenomena described in previous raports that show unfavourable effect on the behaviour of self-tuning controllers can be eliminated effectively by means of relatively simple diagnostic and decisive methods applied in the controller itself. Basic assumptions for diagnostic method based on internal state analysis of self-tuning controllers have been presented below. There are also examples of results obtained in course of simulation tests presented further on. The considerations refer to those controllers that realize the self-tuning operation basing on characteristics of control system start-up.

1. MAIN ASSUMPTIONS OF THE METHOD

As it has been stated before, one of the disadvantages of self-tuning controllers category is obtaining non complete or partially distorted information on dynamic properties of the object under control.

Quite essential part of negative effects of the above cases may be eliminated using the solution of multi-phase algorithm presented in [9] and discussed more detaily in [13, 23, 24].

The functionality of the algorithm is based on the following assumptions:

* cyclic repeatibility of technological process
* occurance of important changes in controlled object dynamics during successive work cycles
* necessity to ensure priority to the technnological process under control, i.e. safe operation procedure
* application of self-tuning controllers fulfilling the requirement of relative aperiodicity.

Papers presented in [23, 24] show that there is the possibility to realize more efficient multi-phase self-tuning process that allows to meet the above listed assumptions and moreover enables:

* to obtain wider and more precise information on object parameters
* to provide few-phase, so called "soft" process of self-tuning for main controller and perform controller's configuration including operation optimisation, if necessary
* to verify current dynamic state of the system and analyse the quality of control, the results of which may be used to build safety procedures EAP), eg. based on expert rules, fuzzy logic rules, etc. [1]

The simulation test carried out comprised three or four-phase procedures of self-tuning as follows:

* phase of identification of the object and preliminary tuning of the controller (I) - phase based on typical identification methods used for cnsidered category of controllers
* phase of recognision of amplification of object (I) and estimation of system operation, correction of controller settings and activation of improving blocks (II) - phase based on short time operation of PD algorithm and analysis of transient process. If necessary, this phase may comprise the start of

"operation safety procedure" if the control quality is recognised unsatisfactory (e.g. oscillation of the adjusted or controlled value has occurred).

* phase of reaching the set value (III)
* phase, if any, of final verification of system operation (IV) - realized at the level of x(t)=xo.

II. PERFORMANCE PRINCIPLES

The characteristic stepsof the method proposed are as follows:

1) classical start of control system based on the technique of object identification, assumed or selected from system library

2) analysis of ststistic error value in phase II:

$$e\ ust = xo /(1+Ko^{*}\ Kr1)$$

where: Kr1 - preliminary amplification of controller defined for phase I
Kro* - amplification of object at level of x(t) = xo

and examination of transient process to see if any oscillation have occured.

If the amplification value is known, and additionally the measurement or estimation {dx(t)/dt]tmax are known, than it is possible to obtain value Tz, important in terms of further system diagnosis and optimisation of configuration selection and dynamic settings of the system.

3) preliminary determination of object control parameters and checking to obtain the warning coefficient value "a", where the value of this coefficient, i.e. predictive estimation of over-control, equals to:

$$a=[xo/Tc(to + 0{,}55\ xo\ Tz/Xm)] - xo/KoKr$$

where: to, Tz, Ko, Xm - object parameters; xo, Kr, Tc, Td - controller parameters.

Principles of practical usage of the method described have been discussed in [10, 12, 13]. Considering the problems mentioned, the analitical form of this coefficient has such an advantage that it may be used in any method of simplified identification, particularly in secant and tangent methods. Analysis of the sign of expression (2) proves the quality characteristics of transient state (e.g. a >> 0 proves over-control, a = 0 - proves aperiodic course, a < 0 - proves creeping of the transient course). Analysis of the numeric value of "a" allows to estimate intensity of the phenomenon particularly to predict the over-control value. It may be essential in term of self-tunung controllers operation based on start-up characteristics analysis to estimate the risk of remarkable integrating over-control values to occur. The risk may be said to be even greater than in traditional control systems.

It is worth mentioning that on having done the analysis of the coefficient it is possible to generate alarms and warnings to operators. Moreover it is possible to verify settings and in some extent, optimisation of selection of the type of the system limiting integrating process.

The Authors have proved, on having done wide simulation tests, that analysis of the above values allows usually not only the selecton of of settings for desaturation but also allows flexible current configuration and supplementary (overlapping) selection of techniques of integrating process limiters (i.e. threshold limits). On the other hand, if operation of integrating course is too weak (i.e. strong negative values of "a") it is possible to correct the course to make it more active (e.g. on having entered proper calculated preliminary conditions for the course) [10, 13].

Finally, one more option of using the analysis of "a" in self-tuning process may result in generating, for extremely high or low values, the messages to operator suggesting further actions or performing the procedure of operation safety, realize by controlling block of the controller

4) analysis of signal value fixed within integrating course of main controller (with no limits)

$$Ui=xo/Ko^{*}Kr2$$

where: Kr2 - controller amplification corrected after phase II

Lots of tests carried out for such controller configuration have proved the following advantages of the system [4, 13, 23, 24]:
* possibility to essentially good matching of controller parameters with real dynamic parameters of controlled object
* low sensitivity of control quality to the used method of main controller dynamics selection
* possibility of using multi-variant identification method, allowing modification depending on set value level
* essentially lower risk of over-control occurence at minimum increase of controlling time
* possibility to create at least 2-3 points within transient state allowing objective estimation of its run and making decision on using safety or emergency procedures.

III. POSSIBLE APPLICATIONS - EXAMPLES OF SELECTED MODIFICATIONS OF CONTROLLER STRUCTURE

1) controllers with desaturation loop type "arw" and others.
The known value of Tz, obtained by using the self-tuning algorithm proposed, has essential meaning for synthesis of sysyems limiting the integrating. Particulary it refers to sensitive systems equipped with desaturation loop "arw". It is possible to determine an uncorrected amplification output value for the loop equal to:

$$Kz=[(to-0,5*r*Tz)-tc/(Ko*Kr)]/[to*Un+Tz(r-1/(Ko*Kr)-Td/Tz)]$$

where: Kr, Tc, Td - settings of main controller
Un - level of saturation of controller output
r=xo/Xmm - level of control of the controller

Relation (6) shows that proper operation of desaturation loop depends essentially on precision of value Tz [10, 19]. Sometimes, in controllers performing more complex tasks (e.g. following-up control, software one or combined software and stabilisation control) the setting of integrating time parameter may be of different form than in universal formulas [16, 23, 24]:

$$Tc=b1\ to + b2\ Tz$$

Considering that fact that the second component of the relation describing the setting is responsible for system operation on leading edge of programme or in start-up phase, then some trouble may occur to have the value Tz correctly determined affecting quality in those sections of transient state. This phenomenon, however, is not so difficult to be managed due to self-correcting funtion applied in settings selection formula (5)
2) alternating structure systems
If Tz value is known the effect of structure change may be used in self-tuning controllers. In case of alternating structure systems (UZS) operating with limited number of switches (typical solution in industrial controlling systems of common use) the only condition to obtain aperiodic transient process is the reduction of switching rule expressed by [14, 21]:

$$S(t) - x(t) + m\ x(t)$$

the parameter C fulfilled the condition [12, 14]:

$$m = 1/d*Tz$$

where: d - coefficient of time reduction constant [14], depending on object identification method applied.
3) algorithm PDPI and PDPID
Further examples, proving that unknown or uncorrect value of Tz may result in negative effects on control system operation, are controllers using PDPI and PDIPD algorithms practically recognised as efficient ones. One of valuable advantages of these controllers is their structural mechanism of protection against over-control. Preliminary differentiating block [10, 15] is responsible for that

effect. The setting of amplification Td1 of the block, the guarantee for aperiodic characteristics of transient process, may be expressed with [10]:

$$Kd1 = (to + 05\ Tz\ xo/Xm) - Tc/KoKr$$

It is easily seem that over estimation of Tz value may lead to increase Td1 value and vice vers. Uncorrect selection of this parameter due to the above effect may result in occurence of positive internal coupling in controller. It hardly ever results in stability loss however, the quality gets much worse (modulation of main course) and additionally, executive devices of typical design get worn much faster.

4) final tuning of the controller and settings verification

An additional support in safety procedures and optimisation of controller dynamics can be provided with analysis of a moment of reaching the set value by signal in integrating course:

$$ui=xo/Ko*Kr2$$

where: Ko, Kr1 - verified, in phase II, object and controller parameters respectively

It allows to make final verification of object amplification value to Koo value and to make final verification of other object parameters and simultaneously further recalculation of controller parameters to optimize them to stabilisation phase conditiions.

4. CHOOSED EXAMPLES OF SIMULATIONS

Below, there are two cases of simulation tests for self-tuned controller leant on classical algorithm of secant; in conventional and multistage (with double stage verification of controller's parameter and over prediction (*))versions. Effect are shown on fig.1 and fig. 2.

On fig.1 shown for a three levels of set value (Xo= 25, 50, 70 %) the runs of control value x(t) for a controller's dynamic leant on popular Reswick's sets and object (Ko=1,5; to=3 sek; Tz=20 sek; c=0,15)

On account of application of two independent algorithms in first phase of verification, there is appropriate two times the time of this phase elongation. There is also noted a great reduction of over-regulation (from 40% to less than 4 % at higher set values).

On fig. 2 shown the runs of control value for the same object and controller in case where the application of sets make instability of control system's work (there was used one from recommended in literature sets: I2)

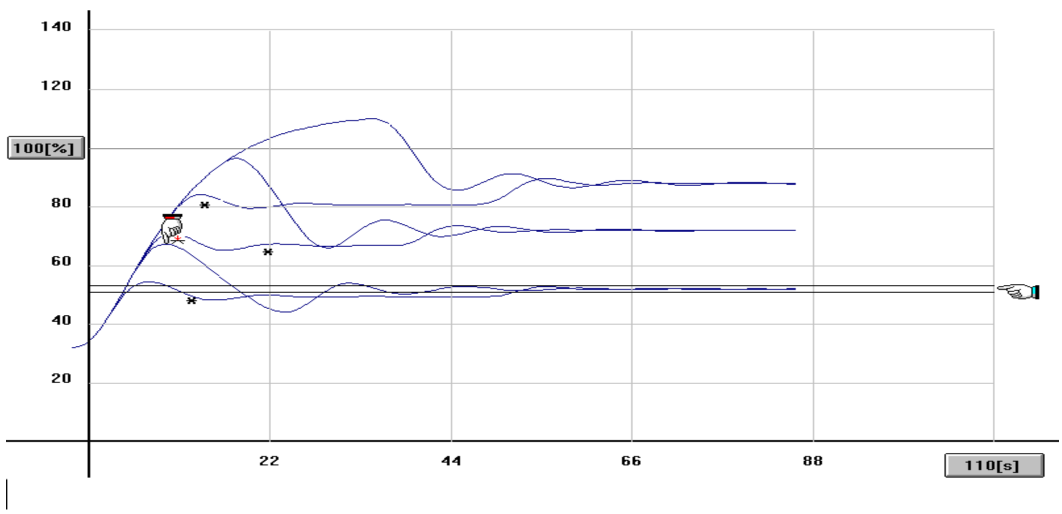

Fig. 1 Runs with Reswick's sets

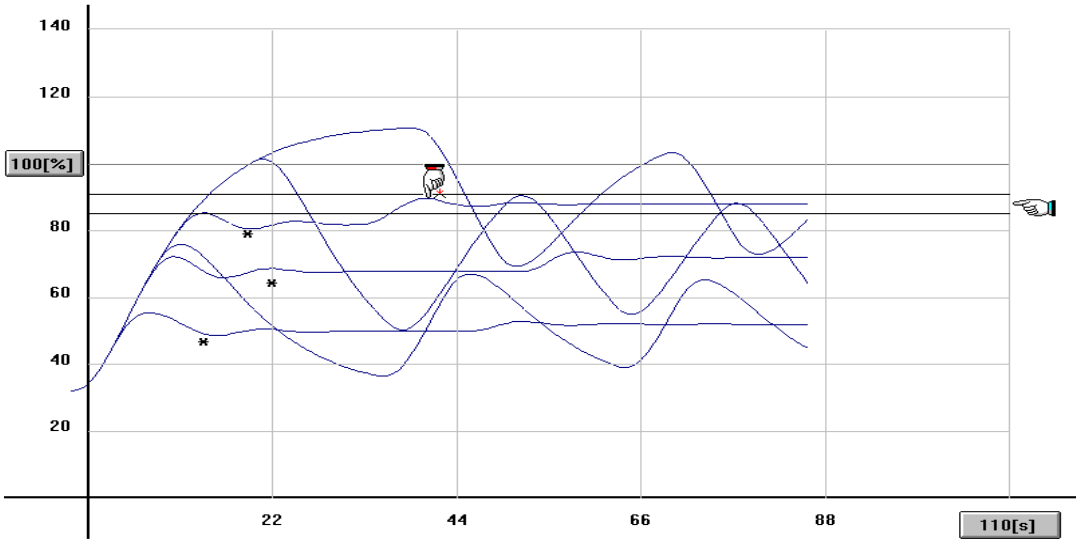

Fig. 2 Runs with I2 sets

It is distinct, that conventional controller based on one-stage self-tuning, can not give the stability (independent of level of set value with a great over-regulation: 112% for Xo=25%. Thanks to mark of verification and internal diagnosis of controller with multi-stage self-tuning, the runs with it"s application (*) are without the failure and give the possibility af acceptation.

5.SUMMARY

Presenting this material the Authors intended to show that it is possible to optimise control system operation making use of the common qualities of self-tuning controllers instead of serious structural or functional changes within the systems. The solution presented allow to use modification techniques for self-tuning controllers. The techniques mentioned may include structure change or introduction of non-linearity and additional correction couplings into main controller structure even during transients process course.Such an approach offers new quality possibilities to create dynamics of self-tuning controllers combining expert systems or classical systems with self-tuning controllers. Such control systems offer new possibilities to designers, producers and users. The range of possible solutions is much greater than in case of classical approach. They may lead to extend controller functionality and improvement of control quality. They would allow to create great number of additional efficient verification and safety mechanisms accompanying control process.

6. REFERENCES

1. Astroem K.J., Anton J.J., Arzen K.E. *Expert control.* Automatica (IFAC), No 3/87
2. Astroem K.J., Haggelund T. *Automatic tuning of simple regulators with specifications phase and amplitude margins.* Automatica (IFAC), No 5/84
3. Banyazs C., Kevicsky L. *Direct methods for self-tuning PID regulators.* IFAC, Identification and System Parameter Estimation, Washington (D.C.), 1982
4. Barzyk G. *Algorytmy weryfikacji doboru nastaw regulatorów konwencjonalnych i samonastraja-jących*. Praca magisterska, Politechnika Szczecińska, Szczecin, 1996.
5. Domek S., Broel-Plater B., Jarmusz M. *Modyfikacja akcji całkującej wieloprocesorowych regulatorów PID*. IV KKN-T „Zastosowanie komputerów w przemyśle"; T.3; Szczecin 1985
6. Halawa J., Galar R. *Uwagi o optymalnych nastawach regulatorów PI.* PAK, No 5/81

7. Hall J. *Process controllers reap uP benefis.*The Industrial & Process Control Magazin, Hilton, 8/83
8. Hoffmeister W. *Prozessregler Auswahlkriterien und Einstellungshilfen.* VDI Verlag, Dusseldorf 1975
9. Jarmusz M. *Analiza możliwości wykorzystania pomiaru maksymalnej...* WUPS, Szczecin, 1985
10. Jarmusz M. *Praktyczne aspekty podst. technik ograniczania akcji całkującej w regulatorach PID.* Opracowanie wewn. NOT-ZRT, Zielona Góra 1985
11. Jarmusz M., Broel-Plater B., Domek S. *Sposób adaptacji właściwości dynamicznych...* PAK, No 5/83
12. Jarmusz M., Broel-Plater B., Domek S. *Wykorzystanie ograniczenia akcji całkującej...* PAK, No 5-6/82
13. Jarmusz M. *Możliwości wykorzystania pomiaru maks. prędkości fazowej...* NOT-ZEiDT Warszawa 1990
14. Jarmusz M. *Analiza przyczyn nieoptymalności układów o ...*Praca doktorska, P.S., Szczecin, 1976
15. Katzenbisser R. *Zur Parameterwahl bei Schaltenden PID...* Regelungstechnik, No2/1978
16. Кулаков Г.Т. *Инженерные экспресс методы расчета промышленных систем регулированиа.* Издательство „Вышейшая школа”; Минск 1984
17. Ogonowski Z. *Samonastrajający algorytm PID w regulatorze EFTRONIK M.* PAK, No 3/1989
18. Proels H. *Verbessertes Anfahrverhalten durch elektronische Regler...* Regelungstechnische Praxis, 10/73
19. Radanowicz T. *Układy ograniczania akcji całkującej w regulatorach cyfrowych.* Praca magisterska, Politechnika Sczecińska, IAP PS, 1986
20. Riollot L. *Identification procedure for linear delayed systems by...* Regelungstechnik, 1/1982
21. Sindelar J. *Regulaczni obvody s nespojite promennou strukturou.* Academia, Praha, 1973
22. Skurjat T., Broel-Plater B., Domek S. *Mikroprocesorowy regulator powszechnego przeznaczenia.* PAK, 3/86
23. Walczakiewicz W. *Algorytm samonastrajający regulatora z eliminacją przeregulowania.* Praca magisterska, Politechnika Szczecińska, IAP PS, 1989
24. Wolski R. *Dobór optymalnych nastaw w regulatorach, szczególnie...* Praca magisterska, Politechnika Szczecińska, IAP PS, 1990
25. Mera-Pnefal S.A. *DTR U486-02 Regulator mikroprocesorowy Eftronik X typ U486.* Warszawa, 1984
26. Mera-Pnefal S.A. *DTR U488-02 Regulator mikroprocesorowy Eftronik XP typ U488.* Warszawa, 1985
27. Hartmann&Braunn *Protronic P.* Frankfurt Am Main, 1995
28. Gulf International *West P406.* Baltimore, 1993
29. Honeywell *UDC 500.* Wien, 1992
30. Yokogawa-Hokushin *SLPC X.* Osaka, 1990

АКТИВНАЯ ДИАГНОСТИКА САМОНАСТРАИВАЮЩИХСЯ СИСТЕМ РЕГУЛИРОВАНИЯ PID ОСНОВАНА НА АНАЛИЗЕ ВНУТРЕННИХ ЯВЛЕНИЙ В РЕГУЛАТОРЕ - ВЫБРАННЫЕ СЛУЧАЕ ПРИМЕНЕНИЯ

Аннотация: В реферате на основании системы управления с самонастраивающимся регулатором работающим в многократном процессе самонастраивания, согласно методу предлогаемому через автора, показано разные возможности текующей оценки выбранных показателей качества. Реферат представляет также несколько методы текующей проверении её динамики, а также несколько элементов её конфигурации имеющих влияние на внутренный эффект в регуляторе работающим в системе самонастраивающимся PID. Реферат также показывает плюсы и минусы исползования техники „fuzzy logic” до анализируемой системы.