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ACTIVE DIAGNOSIS OF SELF-TUNING PID CONTROL SYSTEMS BASED ON ANALYSIS OF INTERNAL PHENOMENA WITHIN THE CONTROLLERS - MAIN PROBLEMS TO BE SOLVED

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

Abstract: Behaviour of PID control system and eventual optimization its work, even for experienced personnel operated it, can present many difficulties. Effectively instrument assisting to personnel in this kind of situation can include built-in helpful algorithm of regulator's state supplied in applicable conclusions system. The paper, according to example of self-tuning PID regulator, will present the work's analysis of control system with showing the possibilities of making conclusion about this kind of control system's work on the basis of phenomena and internal signals of regulator and control systems. Simulated research of proposal solutions, confirmed suppositions about high effectiveness of used verification's method, presented control system.

1. INTRODUCTION

For some time now the trend to use self-tuning controllers in applied automatics systems can be observed. Along with the more and more common use of these controllers several new quality problems have appeared that are related mainly to the following issues:

- optimum self-tuning technique selection, both in terms of identification method of the object under control and selection of dynamic settings of the controller
- optimum controller functional configuration selection
- selection of safety mechanisms securing the process of control against possible failure of self-tuning and configuration procedures

The above was experienced particularly in case of several first self-tuning controllers available on the market and based on algorithmic structure PID using simple, single-phase, non-verified techniques of self-tuning. Extremely unfavourable operating state of such a controller, from the user's point of view, was self-tuning process break-down that required direct intervention of the operator or, what was even worse, resulted in synergy effect of operating state of controlling system remarkably different from expectations in terms of quality. The extent of uccurences mentioned may become even more intensive in case the more advanced control algorithms are used, particularly those basing on effects of controller configuration changes during transient process and on complicated (however not tested to the end so far) modifications of basic algorithms of the controller. On the other hand the group of general nature problems may get greater by some more detailed ones as e.g:

- selection of optimum technique of object identification in given conditions;
- selection of optimum technique of controller dynamic settings selection in view of the task performed (the quality of results strictly connected with object identification technique) [24];
- selection and tuning of blocks improving basic algorithm of the controller, e.g. limiting systems, systems of desaturation or modification of controlling system structure.

There is one more fuction necessary to be carried out considering practical experiences, i.e. **current analysis of controller state and transient process and all decisive implications resulting from such an analysis. [4, 13].** Some forms of these actions may be recognised in design of several self-tuning controller structures however they are most often kept confidential by the producing companies [27-30]. The authors find it reasonable to comprise such a block in functional structure of the controller and allowing to perform the following tasks:

- to increase reliability of controller operation and make the operation easier, particularly for lower qualified staff
- to minimize the risk of possible quality unefficiencies due to hardware
- to ensure so called safe action path in case of partial or complete self-tuning system break-down
- to generate relevant messages, alarms, warnings and instructions for operator in necessary moments.

So far in some present structures few of those tasks are performed occasionally, usually by functions of alarms and blocking or in extreme cases by a request to the operator to make proper decision or undertake remedies. However, such solutions seem to be reasonable only when the operating staff possess enough professional knowledge to solve the problem [17, 22, 25, 26].

Moreover, this requirement becomes even more difficult to be fulfilled if we consider the more and more complicated self-tuning controller functional structures being introduced and forcing so called dedicated constructions of the controllers. It appears to be particularly visible in controlling systems used in now in motorization technology (e.g. complex systems of controlling the driving and active suspension systems fasionable recently) or autopilots for small vessels or planes. The occurence of similar phenomena are observed also in case of some industrial automatics systems using self-tuning controllers, among the others in flexible machining-assemblying centres or technological lines in plastics processing. The vital matter of such applications of self-tuning controllers should be minimum requirement of operator's concern about internal problems of control system and to direct operator's attention towards proper supervision over the technological process efficiency or to supervise vehicle movement.

In Authors' opinion it is difficult to present exact answers at the moment to guarantee complete solution of the problems mentioned. However, basing on theoretical analysis being proved with simulation tests performed for the most typical phenomena occurences some conclusions can be presented. It is possible to present few (however not equivalent to the end) variant algorithmic structures verifying self-tuning controller operation [4, 13, 23].

That is why the Authors would like to concentrate on analysis of those effects only that appeared to affect self-tuning controllers operation undoubtfully and may be eliminated or remarkably limited by means of introducing internal checking-verifying procedured in self-tuning controllers. These problems were widely examined by performing simulation tests [13, 23, 24]. As the range of subjcets mentioned is very wide the materials presented refer exclusively to a group of self-tuning controllers and start-up phase of operation. They form the group of typical solutions applied for numerous servo-mechanisms for vehicles and industrial purposes [22, 25-30].

2. PROBLEMS RESULTING FROM PRACTICAL DETERMINATION OF DYNAMICS OF OBJECT UNDER CONTROL FALLING INTO CATEGORY OF SELF-TUNING CONTROLLERS

Controllers performing the self-tuning procedure on base of start-up phase of cosidering the processes of repeated nature show several advantages. They are quite popular in applications and not so high quality requirement are defined for them particularly if machining or mounting-kinematic tasks are concerned. In practice, however, it appears that fulfilment of those requirements may meet quite essentil difficulties. Among the most serious ones the following can be included:

2.1.The value of amplifying the object is not determined but replaced (depending on simplified object identification technique chosen by producer) with:

a) the ratio value of Xm/Tz (method of secant or derivative methods) [3, 22], where:

Xm - permissible level of object control for u(t)=Umax

Tz - substitute time constant in approximating Kupfmueller's model

One of the simplest solutions of this task is using two measurement locations fulfilling the condition [22]:

$$X1o = 0.15\ Xoz + xp$$
$$x2o = 0.25\ Xoz + xp$$

where: xp - value of parameter controlled at the moment of identification process start

Xoz - range of a given value of the controller

b) derivative maximum value (method of secant or derivative methods) [9, 11]:

$$x\ max = max\ (dt(t)/dt)$$

Value of x max is equivalent to Xm/Tz value whereas the delay is determined by the expression:

$$To = t\ max - x\ (t\ max) / x\ max$$

where: x - current derivative of signal of controlled value

t - (tpp, tkp) - duration of transient process

t max, x max - respectively the moment of maximum derivative value occurence and respective controlled parameter values x(t)

Both solutions mentioned above solving the identification problem generally allow proper selection of controller settings however, they offer slight possibilities to optimise structure changes [4] and make efficient selection complicated in terms of so called threshold techniques of limiting integrating process [10] - among the others, due to the necessity of knowing the K_0 value of amplifying of the object. The self-tuning of controller according to the gradient characteristics of start-up may in case of extreme non-linearity of amplifying cause control quality problems or event the whole process stability problems. It easy to find such a case in controllers using the most commonly used but the most sensitive to mistakes method of secant [13, 23, 24].

2. 2. Remarkable divergencies in estimation of difficulty level using different methods of object identification

It is well known that depending on the self-tuning controller identification method selected the values of model parameters may differ essentially. Even in case of very simple model of inertia type with delay the divergencies may be quite remarkable. As for the older types of self-tuning controllers the divergencies had an effect on the quality of dynamic settings selection of the controller only, in some latest solutions they affect the selection but also the possible modifications of controller structure and so called improving structures. In such situations these occurences may give essentially serious quality effects. The problem mentioned is even more complicated when we realize that it affects the range of activities of designers of self-tuning controllers and limits free choice of solutions. If the identification method is expected to operate in full range of given values then it is necessary to use not one but several methods of identification, depending on given value level. Limitation to use one method only within the entire range gives a risk of incorrect estimation of object difficulty level - having then strong effect on quality of control resulting from respective settings selection. Particularly, using the secant method leads to obtain too optimistic estimation of this parameter of the object that causes among the others [13, 24]:

- assuming too large value of amplifying within the system
- risk of incorrect selection of controller structure or the technique of its change
- risk of failures in selection of auxiliary structures improving the controller, particularly limiting integrating process

The least mistakes of that type are usually found for the objects of low difficulty level (i.e. c<10%, where c=to/Tz) and relatively high level of set values (xo>25%). The phenomenon itself

might be avoidable, independently on give values xo (5-4o%) Xm. For the higher level of set values the effect is more visible for xo>60% Xm, particularly while interferences [13, 24]. The divergencies in estimation of difficulty level in range of its objective value c 0,20 - 0,40 may reach in extreme cases up to 200%.As the most of simplified rules applied in self-tuning controllers for selection of dynamic settings contain at least one value referring to difficulty level comprised in mathematical formula (i.e. for amplifying of controller or for proportionality range) then the results in terms of divergency range estimation are easy to predict. In extreme case the loss of stability may be expected that can be dangerous both for the technological process and executive devices [13].
This effect may occur easily if the control system uses stability rules for selection of dynamic settings having moderate tolerance margins for stability. it may occur also if the controller's structure is changeable using the rule described in [14, 21]. In such a case an incorrect object difficulty level estimation (or in some cases incorrect estimation of delay of object) may result in technical or quality problems, as described in [14].

III. MAIN PROBLEMS OF SELF-TUNING AND PERFORMING CONFIGURATION OF BASIC CONTROLLERS

III. 1: Main problems of settings selection

The above described occurences are related directly to optimization of self-tuning of controllers [8, 16, 24] and they include:

- specific transient processes occurring in self-tuning controllers, particularly in the area of low set values [2, 9, 22]
- problem related to classical application of settings selection rules in controllers to obtain self-tuning control [4, 16, 24]
- problems of stability of self-tuning process and the whole control process [2, 3]
- problems of current checking and veryfication of system operation [4, 13, 23, 24]

Practical usage of different wersions of self-tuning controllers has shown some defects of classical methods of dynamic selection of controllers applied for this group of control systems. One of the most unfavourable phenomena are difficulties to obtain proper operation of the system within the area of relatively low set values (r<0,25, where r=xo/Xm). The phenomena appearing in these conditions have not been met in traditional control systems, e.g.:

- influence of transient processes on control quality related with self-tuning process [13, 23, 24]
- problem of time flow between the self-tuning and the threshold of reaching the proportionality range by the controller [4, 28]
- problem of non-optimum settings resulting from the effect of parameters adopted in identification method to define controller's dynamics [2, 2, 6, 22, 23, 24]
- problems in self-tuning of blocks modifying the structure of controller, particularly ways of desaturation and limitation of component functions including integrating function [5, 9, 10, 12]

The mechanisms of the above phenomena require separate and mostly wide examination. Better knowledge is sensible only when using traditional algorithms in main controllers would result in their applications in few following year's time. Particular attention should be paid to the problem of settings selection of main controllers. Some comprehensive rules of selection commonly used in case of traditional control systems appear more and more unefficient in self-tuning function [8, 16, 24]. It results mainly from previously recognised properties of those settings and moreover:
* comprehensive rules of settings selection do not follow as fast as constructional changes within controllers lat years [8, 10, 12, 16, 24]
* specific courses of transient processes in control systems including self-tuning function within the range under consideration [13, 22, 23, 24]

* essential differences between dynamic parameters determined with definition methods and simplified techniques of identification used in self-tuning controllers [2, 3, 8, 9, 16, 20]

The above described phenomena and possibilities offered by microcomputer technology cause producers to use of very sophisticated formulas to select the settings for self-tuning controllers [1, 2], called "firmware" and difficult to decipher. It has several advantages if the controller operates failurelessly but otherwise makes a lot of troubles in interpretation of failures. On the other hand, considering the law regulations valid nowadays the producers and/or dealers take responsibility to guarantee proper operation of control systems. There for the undertakings are made to transfer the decisions in difficult or critical situations to be made by relevant programme control block [28, 29, 30] of tthe controller, e.g. by activating safety settings package or the function terminating the process.

3.2. Effect of unprecise estimation of parameters of controlled object on operation of most commonly used blocks modifying controller's structure

Except for the phenomena described above, some other factors may affec the behaviour of control system. We mean the unprecise estimation of inertia of object under control, being the secondary occurences to the above mentioned, e.g. in case of simplified model of inertia type with delay it may be unprecise determination of time constant Tz of the model. To determine this value in the controllers using single-phase self-tuning precisely enough appears almost impossible. It results among the others from individual properties of the identification methods used giving usually to high value of time constant Tz in relation to real dynamics for relatively low level of difficulty $c>0,25$. This phenomenon appears less often for easy objects where difficulty level fulfils the condition $c<0,10$. When $c>0,15$ we can observe the trend to over-estimating of constant Tz in relation to real parameters of thee object, particularly using approximation methods, e.g. secant method or maximum derivative method. The grade of mistake of estimation falls within the range from about 40% (for $c<0,20$) up to about 70% (for $c=0,25$). For the difficulty level grater than the latter the trend changes and time constant is minimized in relation to its real value [13, 24]. The range may differ for various identification methods. Quite serious mistakes are noted when using method of characteristic surfaces (commonly recognised as one of the most efficient identification methods). However, the results closest to reality are obtained with maximum derivative measurement metod[9, 20, 23, 24].

The quantitive character of the phenomenon may be described with the range of deviations of Tz value determined in relation to its objective value. Within the range of difficulty levels it could reach up to 50% in minus (with secant method).

Negative results the phenomena described refer both to main structure of controller and its additional function blocks, e.g. the course of structure changes within all typical configurations or different solutions for desaturation loops, particularly those based on "arw" concepption [10, 18, 19], or structure changes. The unprecise estimation of time constant Tz is unfavourable also for controllers of very advanced technology, both in low and high difficulty levels of the object. It may cause:

* generation of zero place of swithing signal S(t) in wrong location that results in non-optimum change of structure with all its secondary effects [14]
* uncorrect selection of amplifying of desaturation loop, resulting in over-activation for higher levels of object difficulty and in under-activation of the loop for lower levels. Both cases are unfavourable in user's point of view. It may lead to over-controlling in case of low level object difficulty and disabling operation of desaturation loop in more difficult systems (structurally), despite it seems easier to be controlled (looking at Kz value) [10, 19]
* non-optimum selection of parameters of preliminary differentiating block in controllers of PDPI and PDPID structures. The results have been shown among the others in [10, 15].

What is more interesting, possible errors in estimation of parameter Tz may be have positive effects for integrating block of main controller. It occurs when if the selection for the integrating block setting was done concerning Tz and to. In such a case self-originating trend to limit the effect of unfavourable domination of integrating function in transient states [10, 12]. It seems the disadvantage of most universal formulas of settings selection, forcing the usage of systems limiting integrating function or operator's intervention.

4. FINAL REMARKS

Brief overview of main disadvantages of self-tuning controllers considered above in this paper gives an overlook on possible areas of operational risk that the producers or suppliers of the equipment can experience as well as its potential user. Very special legal regulations in case of self-tuning controllers referring to the producers and the users, makes it necessary to provide wider examination and testing of self-tuning controllers and development of their functional structure towards minimization of effects having been described above. In Authors' opinion it can be achieved using relatively simple means, i.e. expert techniques or fuzzy logic systems. Interpretation and compensation of negative effects in both solutions may base on great experience about exploitation and rich experimental material from simulation tests. The practical aspects referring to the above problems shall be presented by the Authors in following raports.

5. REFERENCES

Literature is commonly for this paper and paper: ”ACTIVE DIAGNOSIS OF SELF-TUNING PID CONTROL SYSTEMS BASED ON ANALYSIS OF INTERNAL PHENOMENA WITHIN THE CONTROLLERS - SELECTED APPLICATIONS” and published there (also in this proceedings).

АКТИВНАЯ ДИАГНОСТИКА САМОНАСТРАИВАЮЩИХСЯ СИСТЕМ РЕГУЛИРОВАНИЯ PID ОСНОВАНА НА АНАЛИЗЕ ВНУТРЕННИХ ЯВЛЕНИЙ В РЕГУЛЯТОРЕ
- ОСНОВНЫЕ ПРОБЛЕМЫ ДЛЯ РАССМОТРЕНИЯ -

Аннотация: В эксплуатации находится большое количество регулируемых систем основанных на разных версиях алгоритма PID. В зависимости от уровня модификации этого алгоритма может он знагительно отличаться от моделя представленного в литературе. Поведение такой системы регуляции и возможно оптимальная работа, даже опытным специалистом обслуживающим её, может создать много трудностей. В реферате на примере самонастраивающегося регулятора PID представлен анализ работы такой системы вместе с показанием возможности работы такой регулирующей системы на основании явлений и внутренних сигналов регулятора и системы регуляции. Симулированные исследования предлогаемых решений подтвердили предположение о высокой эффективности использованного метода проверяния системы регуляции.