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THE APPLICATION OF REAL-TIME ADAPTIVE CONTROL TECHNIQUES TO INDUSTRIAL PROCESSES

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Abstract: As a research topic, the adaptive control were always considered a controversial one because of "the system can work well enough without it", or "adaptive control is too complex", or "adaptive control will cause you more problems than it solves". The paper's aim is to retrospect on the theoretical and practical achievements related to adaptive control of some industrial processes, to bring out the arguments for and against adaptive control and finally to decide upon new directions of inquiry which are open to improvements of manufacturing processes real time controlled and monitoring. In this manner, the paper hopes to be a little brick in the building of a bridge between theory and practice in adaptive control.

1. INTRODUCTION

The adaptive control, as a research topic and automation methodology is known for technical systems since about 60 years ago. During all this years the domain were considered a controversial one, by one hand because the impression that "the system can work well enough without it", and by other hand because many workshop engineers believe that "adaptive control is too complex" or "adaptive control will cause you more problems than it solves" [2]. There is something truth in both sentences unfortunately, but many theoretical aspects of adaptive control are simple enough once we can proper understand them. A single step remain in order to apply the theory much closer in practice, understanding the real causes because things go wrong if they do and when.

Reviewing the technical literature in the field, a relatively large gap between theory and practice is easily noticed especially in industrial processes [3]. The reason is that the theoretical knowledge is usually not in a form that can be made directly applicable and because of this the research in this field is at the moment in shadow or hidden. It's the time to reopen the old books with respect to adaptive control area, and who knows, maybe will have a happy end this time.

The most important characteristic of adaptive control systems is declined by gathering of information about an unknown process closed loop during operation and by making changes in their control laws.

A generally accepted definition for the expression "adaptive control" is not yet available. As a most widely accepted description, an "adaptive control system" can adjust his behavior to the changing properties of the controlled process and his signals.

2. THEORETICAL ASPECTS

A lot of ways to realize adaptive control system are known, but most of them can be divided into two main groups: feed-forward adaptive controllers and feedback adaptive controllers [1].

In the case of first group, there is no "inner" closed-loop signals in order to adapt the process parameters. The process properties are recognized by measurement of their signals which describe the operating conditions. The variation of process parameters is well known or the parameters can be calculate and stored in a data base. The operating conditions are compared with the designed parameters and, when a certain gap appears, the controller adjusts process parameter. The advantage is a fast reaction to process changes, but only if the process signals change slowly in comparison with the process dynamics. The disadvantages are: no reactions to the unpredictable changes of operating conditions, external disturbances or unmeasured parameters are neglected, a large amount of parameter storage is necessary; the number of controlled parameters must be very small otherwise the parameter changes will be to slow. In conclusion, such of feed-forward adaptive controllers (figure 1) are good for industrial processes which are simple or with a well known behavior.

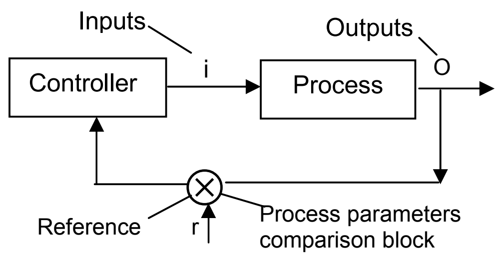


Fig.1. Basic feed-forward adaptive control

In the case of second group, the process behavior cannot be directly determined by process signal measurements. The structure of this type of feedback adaptive controllers are characterized by the following: the changing operation conditions can be grasped by measurement of internal close loop signals, the close loop signals flow through a second feedback level, the adaptation of parameters are done by an additional feedback level. These adaptive control systems are divided into two subgroups: direct adaptive control systems and indirect adaptive control systems.

- The direct adaptive control system (no dual adaptive controllers – named by other authors [2]) are characterized by the fact that it minimizes a performance criterion taking into account only current process inputs, present and past values of control loop signal, and no information about estimates future working conditions. Most of all industrial application are based on this model of adaptive control and uses a scheme as is shown in figure 2.

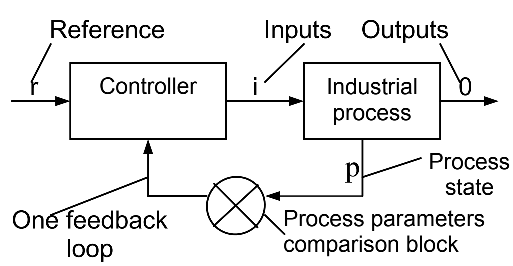


Fig. 2. Direct adaptive control scheme

-The indirect adaptive control system (dual adaptive controllers – named by other authors [2]) is characterized by the fact that it optimizes a performance criterion using a lot of data gathering for estimation. This type of adaptive system generates an optimal control of process behavior and for this reason it must be an active self learning system. To design such of optimal indirect adaptive control system is a very complex job and, therefore, is not yet suitable for practical implementation. If the tasks for adaptive controller are reduced only in optimizing the performance criterion, then the disadvantage of complexity is diminishing and the deterioration in control performance can be accepted for industrial application. An indirect adaptive control scheme suitable for uses in industrial application is shown in figure 3.

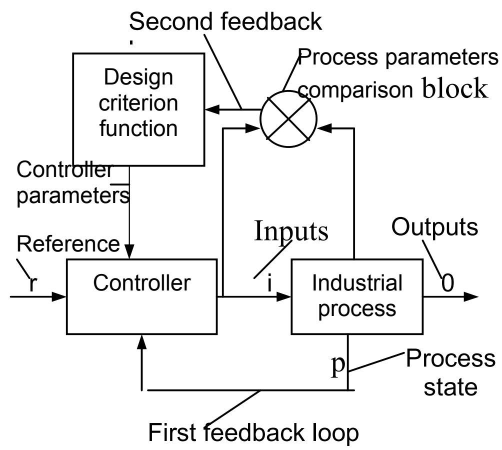


Fig. 3. Indirect adaptive control

For practical implementation of feedback adaptive control the work can be divided in three steps [3]:

a) Comparison of closed-loop behavior;
b) Calculation of the process parameters based on the adaptation algorithm;
c) Adjustment of the controller.

3. ADAPTIVE CONTROL APPLICATIONS IN INDUSTRIAL PROCESSES

The structure of a generic real-time program package for parameter adaptive control of single-input/single output processes using analogue-digital and digital-analogue converters is shown in figure 4. The presented application in this paper is based on it.

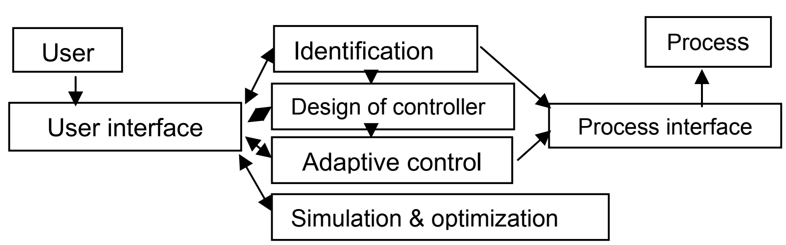


Fig. 4. The structure of an generic adaptive control system

3.1 Temperature control in the cooling system of heat treatment workshop

In the figure 5 a schematically description of a cooling bath for heat treating workshop is presented. The cooling bath system consist of a cooling bath (CB - containing the hardening compound) having the bottom and breast walls in direct connection with the cooling water circuit, a water tank (WT), a temperature transducer (TS), an emergency valve, an electrically driven valve (EV) which control the water flow, a coolant pump (P), an adjusting control system and a PC. The input signals-(i) is the hardening compound temperature T^0. The output variable-(o) is U and is fed to adjust the electro valve. Because the process is slowly reacting, the sampling period was selected to be 5 seconds. In order to control the temperature online and in real-time, a PC and analogue - digital and digital – analogue converters are used. The algorithm for control and optimization is simple and the interface is friendly; No knowledge of adaptive control is required from operators.

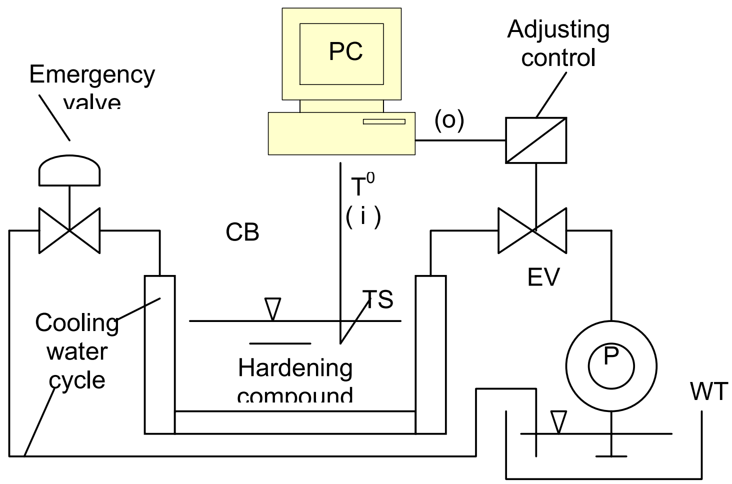


Fig. 5. Temperature control of cooling bath

The presented adaptive control system was developed with the help of a small industrial partner. The simplicity of execution, the performance obtained and the low cost of the implementation, helped the manager to decide in using the same scheme in other application, for adaptive control of water flow-rate, in order to reduce the waste.

3.2 Work parameter control in the metal cutting processes

In this type of application, both, the theory of adaptive control and especially the implementation are more complex than in above mentioned example. The reason is the specific of phenomena implicated, which are insufficient known and hard to model and control through a logical algorithm.

The physical controller of adaptive control of optimization (ACO) should not be separate from the machine tool this time. For example in figure 6 is presented a conceptual construction of ACO based on CNC turning machine tool. In this vision the maintenance interface must display, if necessary, a color graphics, information for trouble - shooting and a three - dimensional version of the part being machined in real - time.

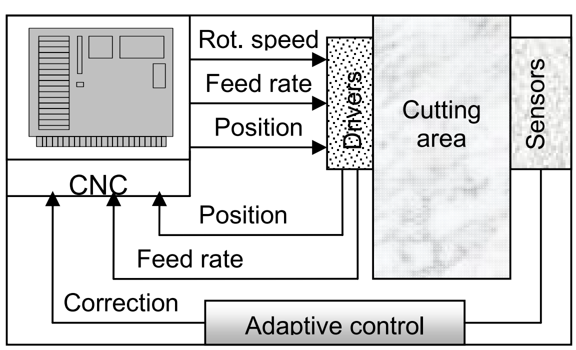
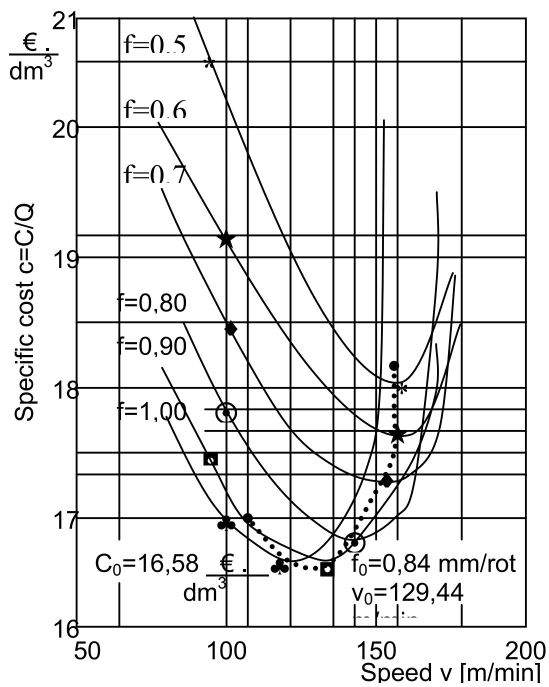


Fig. 6. CNC & ACO machine tool

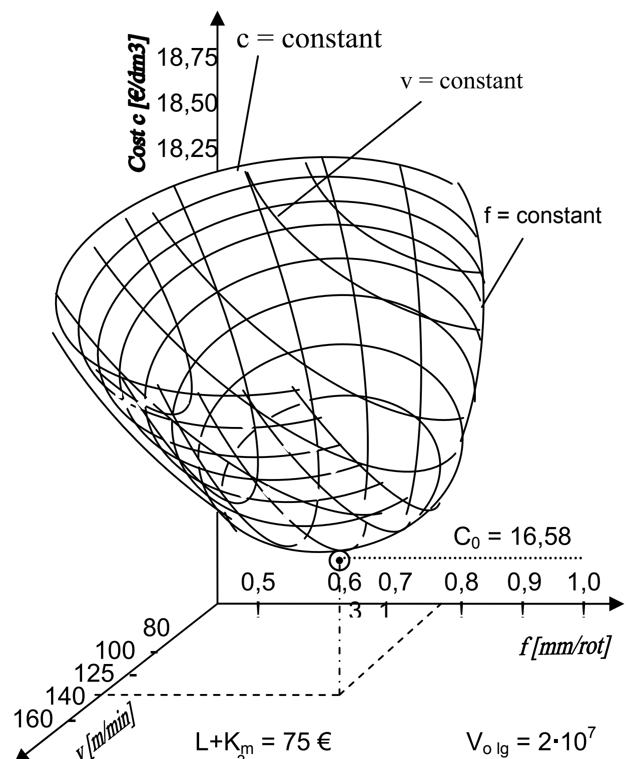
In the area of machine tool-process control it can be said that the application of adaptive control principles is lagging behind the development of the theory. We must mention here, regarding on the Romanian research work in adaptive control of machine tools, the name of Prof. Eugen Dodon, which has created in Timisoara, in the 80^s a really school for researchers dealing with the aspects of adaptive control of metal-cutting processes.

Optimum parameter setting proves inadequate in the dynamic optimization by a lot of reasons. Only two of great moments are mentioned for now: by one hand, usually the numbers of working condition which must be set and controlled are grater than one, and by the other hand the parameters variation is nonlinear one, as you can see in the figures 7 and 8. The transfer - function representation is a hard work and the constraints are in a great many and in a large measure unknowns.



$L+K_m$ = 75 € mm³
W_T = 1,5 €
T_W = 1 min
$V_{o\ lg} = 2 \cdot 10^7$
l = 500 mm
d = 100 mm

Fig. 6. The specific cost variation c dependin of feed rate f and speed v



$L+K_m$ = 75 € mm³
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$V_{o\ lg} = 2 \cdot 10^7$
l = 500 mm
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Fig. 7. Graphical solution of transfer function for adaptive optimization

The answer to these requirements is: complex controlled and verified integration between organization, product design, know-how, machine tool design, and technology. A quarter of century maybe will be enough time for expert system technology to mature and to be included as a built-in component of a machine tool.

3.3 Open issues and remarks on AC applications in the cutting processes

The introduction of flexible manufacturing machine tools and the increasing of production automation is a gradual process. It depends on the extent of production tasks, exactingness concerning flexibility, automation, desired productivity and financial resources of industrial company. All these require a great number of CNC and DNC machine tools, the use of more sophisticated numerical controls, computers and advanced technologies.

For the next decade, new sensors, coupled with knowledge-based systems, will make it possible to automate the adjustment in real-time of working parameters and the diagnosis of routine machine tool failures. The knowledge-based system will works within a software based environment, which uses on-line forces, wears, temperature, roughness, and so forth sensors, to record events at each stage of work piece cutting process.

For example, tool wear and stresses, and cutting time are simultaneously monitored and modified based on reference model. The adaptive control system of the metal cutting machine tool will directly command the end-actuators, which change the cutting parameters.

For the control and support the simulation technique is used. Future development is based on the technologies such as: virtual reality, rapid prototyping, visual simulation, laser machining, high-speed cutting, use of neural, fuzzy and genetic algorithms etc. The result will be the reduction of production costs, shortening of flow times, production based on the clients' orders and considerable shortening of product development cycle.

With all these improvements in the machine tool industry, the plant of the future will be more autonomous and able to operate in just-in time mode, with minimum good-in and good-out locations on each side of the access bay. Undoubtedly, the research on developing a new design process for machine tools will contribute to remodeling of entire manufacturing systems.

4. CONCLUDING REMARKS

The advantage of application of adaptive control techniques is obviously for single-dimensional processes, because its relative simplicity and low cost of implementation.

In the adaptive control experiments on turning, simple thermocouple and force measurement dynamometers have been advocated for adaptive control. Future work must be devoted to the refinement of these existing sensor schemes, which must be carefully documented for a wide range of commercial cutting tools. In addition, the hardware for these devices must be ruggerized and tailored to the geometrical constraints of various machine tools. In this context, several researches projects in the future, considered as priorities for the development of an IMS are possible.

The paper's aim is to retrospect on the theoretical and practical achievements related to adaptive control of some industrial processes, to bring out the arguments for and against adaptive control and finally to decide upon new directions of inquiry which are open to improvements of manufacturing processes real time controlled and monitoring. In this manner, the paper hopes to be a little brick in the building of a bridge between theory and practice in adaptive control.

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