Design of Hierarchical Intelligent Control System of Complex Chemical-Technological Process

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Abstract: The paper is devoted to the problem of chemical-technological processes control on the basis of active expert system with purpose to improve quality of final product and to increase production safety for industrial objects, which are in exploitation for sufficiently long time. The ways of increasing efficiency and safety of production processes with account of modern requirements to production quality and equipment on the basis of intelligent control are discussed.

Key words: chemical-technological process, expert system, intelligent control

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1. Introduction

The problem of maintenance of the quality and the safety of production is always topical, especially for chemical-technological processes (CTP), which are continuous in time. Any stop of the process (and subsequent start) requires time and additional expenditures and lead to decreasing the life resources. The error correction in control procedure also requires significant time that can result in outcome of defective production [3,4].

The issue of production safety also requires new approaches, taking into account depreciation and obsolescence of equipment, on which processing of fire-explosion-dangerous matter and in view of modern requirements, insufficient level of informatization and automation of production [1,2,5].

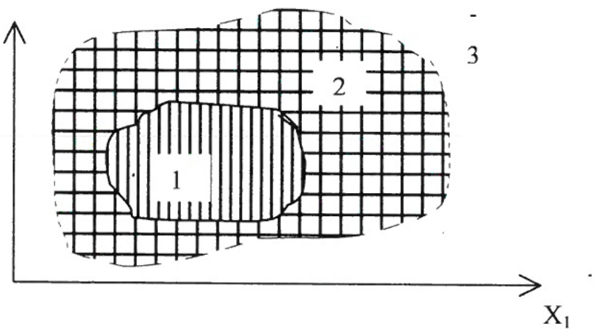

Figure 1. Space of Possible Chemical-Technologi-cal Processes Operation;

1 - domain of nominal modes;

2 - domain of operative control;

3 - domain of emergency modes,

X –vector of CTP parameters.

2. Control object. Problem statement

The CTP have a number of particular properties from the point of view of control theory. They are multivariable non-linear dynamic objects for which practically it is impossible to elaborate the precise analytical description as a whole.

And the object operation takes place in the conditions of substantial uncertainty. The attempt of formalization of account of many factors action to the object usually fails.

The analysis shows that it is possible to divide the space of change of CTP parameters into three enclosed domains; shown in Figure 1, where 1 - domain of nominal modes; 2 - domain of operative control; 3 - domain of emergency modes.

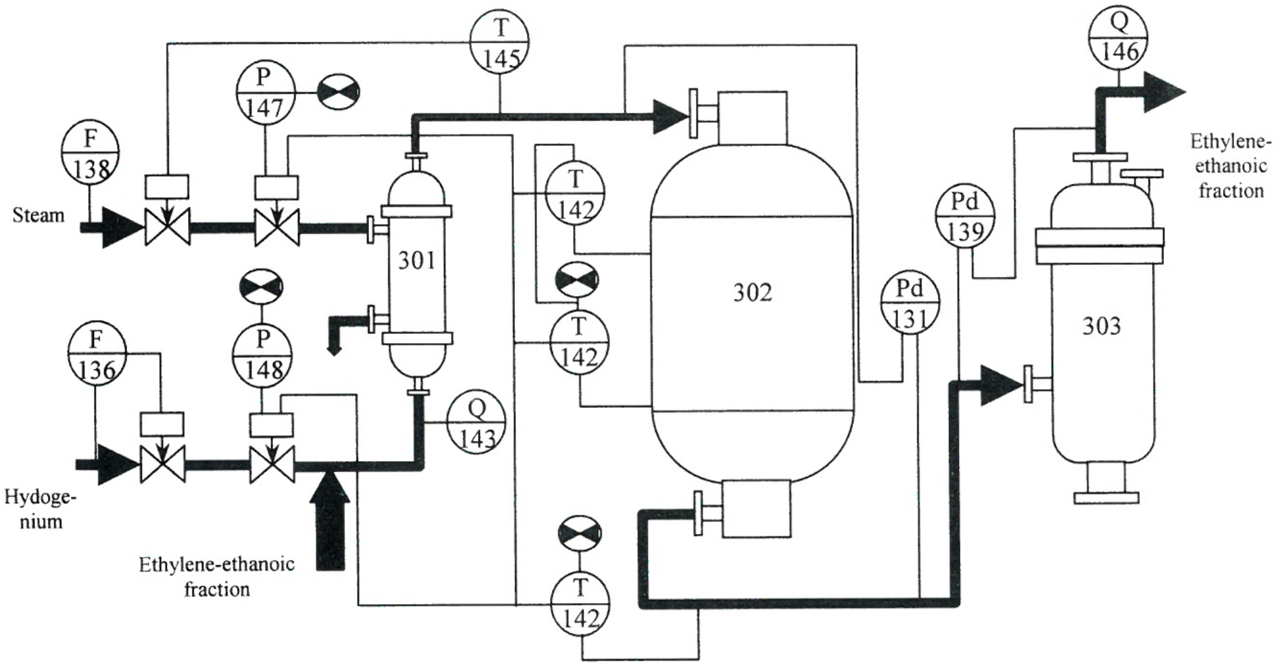

Figure 2: Production Process of Pyrolis Gas Separation

There is an analytical description of the processes for domain 1. In practice, simple determined models are developed for this area, and the classic automatic controllers are to be designed. Usually these controllers belong to the class of PI and PID controllers. Under the conditions of stability of the factors acting to the object, when it is necessary only to stabilize the parameters of control object, PID controllers provide essential quality of control processes. The domain of operative control (domain 2) represents an area of such changes of parameters, when the simplifications, used at the construction of analytical relationships already, are impossible to take into account, but practically it is difficult to represent them formally, then the interference of man in control procedure is necessary. Otherwise, the prolonged transients with decrease of production quality or exit of the process parameters to the third domain (domain of emergency modes) are possible.

At the occurrence of emergence mode, the control is completely carried out by man. In this case it is necessary to make decision of prolongation of further operation, recovering the failures by the way of switching to the backup equipment or even about evacuation of the staff.

Thus, today man-operator is a necessary link in the control loop of CTP. Man uses the experience accumulated in the work with the given object and intuitively compensates the effect of unfavorable factors to control object.

However, there is a following problem: the behavior of a man is inadequately predicted, especially in critical situations. Practically, it is difficult to control a considerable amount of parameters of the process.

Below the installation of separation of pyrolise gas, concluding about 150 controlled parameters, is considered as the control object. Moreover, 10 men carry out the control of the installation. Each of CTP parameters is important, as the object is located at the large area, and it is necessary to control not only the parameters of some processes, but also the lines of supply of the raw materials, reactants etc.

As several men control the process, they should interact with each other and make the joint decisions that require a certain time. In the case, when the competence of control staff is not sufficient, the decisions are made at higher level of control hierarchy, that also requires time. Practically, the following actions are to be fulfilled: if the correction of situation at the given level of control hierarchy fails, the installation or its part stops with all the consequences ensuing there from. Then the search of decision, recovering the failures and start of the installation in real time frequently fail, as it is necessary to interact by several hierarchic levels of control and there are large delays at the transmission of information between levels.

Table 1

Possible accidents	Reasons of accidents occurrence	Ways of accident-shooting
1	2	3
Increase of acetylene content in ethylene-ethanoic fraction **after** hydrogenation	1. **Low** temperature of ethylene-ethanoic fraction at the input of reactor (302) 2. **Insufficient** supply of hydrogenous fraction	1. **To increase** the steam supply in preheater (301) 2. **To increase** the supply of hydrogenous fraction
Uprating of the temperature of ethylene -ethanoic fraction at the output of reactor (302)	1. **High** temperature of ethylene ethanoic fraction **after** preheater (301) 2. **Large** content of Hydrogenium in the mixture of ethylene - ethanoic fraction fed to hydrogenation	1. **To lower** the temperature of ethylene -ethanoic fraction after preheater (301) 2. **To reduce** the supply of hydrogenous fraction to hydrogenation 3. **At the further** temperature **rise** to switch off the reactor (302), **to release** the pressure from it
Large pressure difference in catalyst layers of reactor (302)	The catalyst **is clogged** with coke.	**To switch off** the reactor for washdown or overload of catalyst
Large pressure difference for filter (303)	**Driving** the filter by catalyst	**To supply** the ethylene-ethanoic fraction apart from the filer (303), to switch off the filter for cleaning.

As an example, we shall consider one of the stages of the process of pyrolise gas separation: the process of hydrogenation of acetylene at palladic catalyst (shown in Figure. 2). The process is carried out with the purpose of minimization of the acetylene content and its homologues in ethylene-ethanoic fraction (EEF) or propane-propylene fraction (PPF) for producing ethylene and propylene of high concentrations (for the processes of polymerization). For this purpose, EEF is mixed with Hydrogenous, heated in heatexchanger and fed in the reactor (302), where the process of hydrogenation takes place. Thus, the acetylene transforms to ethylene and ethane (or propylene and propane). The output characteristic of the process is the content of acetylene and its homologues after hydrogenation (Q146). The control of reaction is made with the aid of change of steam flow rate (F138) in the heatexchanger, i.e. the change of initial temperature of the mixture, and the change of the flow rate of Hydrogenous (F136). The following factors affect the process: instability of the quantity of flow rate of the fed EEF (PPF), nonconstant structure of acetylene and its homologues in EEF, change of the temperature of ambient air, change of the state of catalyst in the reactor.

The possible problems, which can occur in the case of errors in control process, are: increasing the acetylene content at the output of installation (Q146), decreasing the lifetime of expensive palladic catalyst, the thermal destruction of reactor (302) with implosion of Hydrogenous.

So, the control of installation is carried out with the aid of two loops. In one of them the temperature at the input of reactor (T145) is automatically held by means of the quantity of steam (F138) fed to the heatexchanger.

Another loop, providing the regulation of supply of hydrogenium, is open loop, and the active role in

control procedure is the human factor. The special rules of control and preventing the emergency situations are developed for the staff controlling the given process, some of them are shown in Table 1.

The construction of closed-loop, providing the stabilization of the given composition of acetylene, by means of regulation of the quantity of hydrogenium and the temperature of initial mixture, was not made by designers of the given installation because of the technical complexity of construction of automatic controlling device.

Thus, the problem of development of intelligent control system is topical, allowing to take into account non-formalizable disturbances, to use the experience of controlling staff and to ensure the control of the given CTP in all points of the space of change of working parameters (up to emergency modes). The development of the given system will allow to decrease down to the minimum the influence of subjective and poorly predictable human factor acting to the controlling object, and also to speed up the process of control decision making.

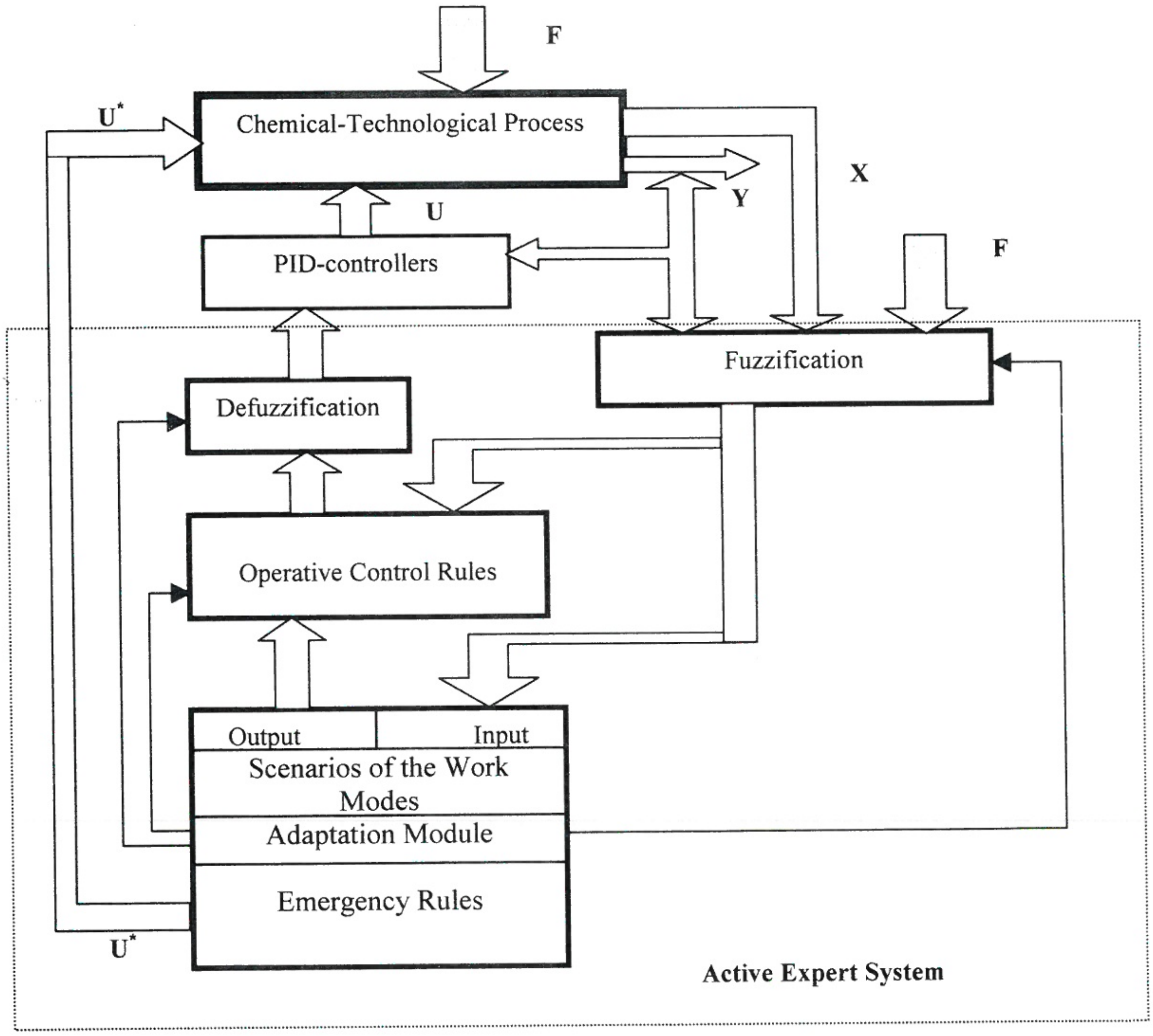

Figure 3. Control System of TCP with Active Expert System

3. The suggested approach to design problem

The suggested control system is based on the use of active expert system and belongs to the class of hierarchical multi-level systems, including the available control tools as the composite part of the system (Figure 4, where Y - output of CTP, X - state of CTP, F - external factors of instability, U and U^* - groups of the control actions at CTP).

The application of the expert system is justified from the point of view of transparency of making certain decision (i.e. capability of explanation to the man of decision making reasons) and capability of simple modification of specific rules, each of which responds to some domain of the space of working parameters.

For each domain of the change parameters of possible operational mode (Figure 1), the control level is designed with the appropriate group of rules (productions) "IF THEN". On the basis of output data obtained from control object (coordinates of the point of operational mode) and a prior information of the factors of instability, the decision is made with the aid of concrete groups of rules corresponding to the given domain of the space of working parameters.

The groups of the rules differ from each other mainly by their right side. The groups of the rules of operative control definitely change the parameters of PID-controllers, i.e. the right side contains the instruction about the change of some numerical values. The rules of control in emergency situations contain in their right side some logic actions, which are to be executed (e.g. to switch on the alarm system or ventilation, to switch off the supply of raw, etc.). Thus, each group of rules has its own group of actuating devices.

As it was mentioned above, the levels of hierarchical control system provide the maintenance of high quality of production control and are organized by a principle of increasing the intelligence from a lower to an upper level with appropriate decreasing the control accuracy.

For example, considered in the given paper, the groups of the rules of lower (executive) levels corresponding to operating conditions 2 and 3 (Fig. 1) were designed. At the following level of hierarchy, the group of control rules for the shop with several installations was constructed, that allowed to provide the coordination of operation of the separate installations. Thus, the group of the rules for single installation corresponds to the level of operator controlling the separation processes, and the group of the rules of the following (third) level of hierarchy corresponds to the level of shop chief, responsible for whole operation of all installations. The rules of active expert system were determined on the base of production process set of scenarios, with account of number of working parameters and their interaction. For concrete parameters of CTP the membership functions of fuzzy sets were set, which can be individually adjusted for the concrete object (i.e. the concrete type of CTP). By means of supposed procedure the numerical values of parameters are to be processed by appropriate group of rules of expert system, which makes decisions concerning control actions in given instant.

The separate unit of control system executes the function of adjusting system at random change of object parameters. The adjustment is made at level of control object parameters – i.e. parametric adaptation or at level of concrete rules (deleting, change) – i.e. structural adaptation of the system.

Conclusions

The problem of development of intelligent control system for complex CTP on the basis of active expert control system is discussed. The offered control system provides the improvement of CTP control process quality and increases their safety. One of important functions of the given system is minimization of the time of control decision making.

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