DECOMPOSITIONAL APPROACH IN SOLVING THE POTENTIONAL HAZARD TECHNOLOGICAL PROCESSE PROBLEM CONTROL ON METHANE CONVERSION UNIT EXAMPLE

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ДЕКОМПОЗИЦІЙНИЙ ПІДХІД У ВИРШЕННІ ЗАДАЧІ УПРАВЛІННЯ ПОТЕНЦІЙНО НЕБЕЗПЕЧНИМИ ТЕХНОЛОГІЧНИМИ ПРОЦЕСАМИ НА ПРИКЛАДІ БЛОКА КОНВЕРСІЇ МЕТАНА

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The decomposition principles application for solving the problems of controlling a potentially hazardous technological process is presented using the example of ammonia synthesis. The process of ammonia synthesis is considered as a complex technological system (object). The analysis of the technological process made it possible to formulate a general control criterion. The multicriteria control problem as a result of the decomposition approach is reduced to the single-criterion hierarchical optimal control problem

Keywords:: *control, decomposition, potential hazard*

Представлено застосування принципів декомпозиції для вирішення задач управління потенційно небезпечним технологічним процесом на прикладі процесу синтезу аміаку. Процес синтезу аміаку розглядається як складна технологічна система (об'єкт). Аналіз технологічного процесу дав можливість сформулювати цілі і формалізувати критерій управління. Багатокритеріальна задача управління в результаті декомпозиційного підходу зведена до однокритеріальної ієрархічної задачі оптимального управління.

Ключові слова: *управління, декомпозиція, потенційна небезпека*

Представлено применение принципов декомпозиции для решения задач управления потенциально опасным технологическим процессом на примере процесса синтеза аммиака. Процесс синтеза аммиака рассматривается как сложная технологическая система (объект). Анализ технологического процесса дал возможность сформулировать цели и формализовать критерий управления. Многокритериальная задача управления в результате декомпозиционного подхода сведена к однокритериальной иерархической задаче оптимального управления.

Ключевые слова: *управление, декомпозиция, потенциальная опасность*

INTRODUCTION

Reducing energy intensity, material consumption, saving raw materials, increasing productivity and quality of products is one of the urgent problems of any modern production. The growth of general production capacities and the complexity of technological schemes lead to an increase in the likelihood of various types of pre-emergency and emergency situations, as well as to an increase in the severity of their possible consequences for personnel, equipment, and the environment, up to and including environmental disasters. Therefore, the tasks of creating flexible automated monitoring and control systems with significant functional reserves, registering emergency deviations and providing a safe exit from them are of paramount importance. All this requires a more accurate systematic approach, more complex mathematical models, new approaches and control methods. The paper analyzes the technological process at the conversion unit (taken into account its potential danger). The main features of the process from the point of view of creating a control system are highlighted. The main risk factors for the occurrence of pre-emergency and emergency situations at the methane conversion unit are identified. The methane conversion unit is considered as a control object. Based on a systematic approach, the goals of process control are defined.

FORMULATION OF THE PROBLEM

Ammonia production is one of the most potentially hazardous (explosive) chemical industries. The class of potentially dangerous production facilities includes those where the reaction capacity of the processes under certain conditions may exceed the permissible capacity of the equipment (technological units and reactors where the technological process takes place or the equipment installed on them), resulting in fires, explosions, and environmental pollution. Similarly to the power factor, different parameters are used in different processes: temperature, pressure, etc. The conversion unit is intended for industrial production of hydrogen, which is later used in the preparation of a nitrogen-hydrogen mixture (NHM) for fixing air nitrogen in the production of ammonia, which is the basis for the production of ammonia fertilizers and many synthetic materials. The features of the methane conversion block can be formulated as follows:

- Potential block hazard. The technological process proceeds at high temperatures and pressures, which means that the risk of possible failures must be taken into account. When developing a methane conversion control system, an approach should be taken that reduces this risk.
- Two sequential steps existence of processing during conversion.
- The interdependence between the main parameters of the conversion process and the entire preparation stage. For example, the interdependence between the concentration of methane in the semi-finished converted gas at the outlet of the tube furnace (the first converter) and the concentration of methane in the converted gas at the outlet of the conversion unit (in the process gas).
- The primary determining role of conversion in terms of the entire thermal regime of the tube furnace and the quality of the final product of the conversion unit, as well as the general basic resources used for technology flow rate.

The conversion block, and, in particular, the tubular furnace (the first step converter), is one of the most potential-hazard objects of the ammonia synthesis chain from natural gas.

The development of automated control systems taken into account to reduce the risk of accidents and prevent the most likely formalized situations that may occur at the control facility allows you to organize control in a new way, thereby increasing the reliability of the object's operation. This brings to the fore the such tasks solution as:

- Research and analysis of technological processes occurring on the conversion block, its analysis as a control object and the risk factors study;
- Technical and economic generalized indicators analysis, the main risk factor for accidents at the facility identification and its consideration when forming the criteria for optimal control of the facility;
- A special role is played of the general problem formulation of conversion unit optimal control, its decomposition, as well as the hierarchical structure construction of the methane conversion unit control system.

ANALYSIS OF THE RESEARCH

The conversion process proceeds in two stages. At the first stage – in a catalytic converter of the first stage (a tubular terraced two-tier furnace) at the output of which converted gas with a concentration of methane of 9…11% is obtained. The resulting semi-finished product enters the second stage converter (mine converter) with the final product of conversion – process gas (converted gas with a concentration of methane in it 3…7%). The technological process proceeds at high temperatures and pressures.

The most important measured parameters that characterize the conversion unit operation and affect the final product produced by the ammonia synthesis unit are: x_1, x_2 – the converted gas semi-finished product current temperature values at the exit of the first and second furnace chambers; Y_1 – the methane concentration current values in the converted gas at the exit of the first stage converter; Y_2 – the methane concentration current values in the process gas at the conversion unit exit. The semi-finished converted gas temperature coming out of the reaction tubes (x_i) is measured at the exits from the first-stage converter furnace chambers. These temperatures characterize the thermal conditions inside the furnace chambers of furnace. The heat regime in the furnace chambers, in turn, changes depending on the amount of fuel gas supplied to the burners: $\Gamma = \{ \Gamma_i \}\ i = 1, \dots, n$ is taken as a vector of control actions.

The main control goals are the following:

1. The resources cost per conversion minimizing.
2. Losses minimization from pre-accident and emergency situations (minimize the risk of accidents at the facility).
3. Methane concentration minimization in the converted gas at the conversion unit output.

The flow rates of both raw materials and fuel gas for maintaining the thermal regime in the furnace chambers of a tubular furnace are the main conversion flow rates.

The converted gas semi-finished product temperature decrease at the outlet of the furnace chambers compensates not only for the reduction of fuel gas costs for the technology, but also for the reduction of the heat load on the reaction pipes of the furnace chambers, reducing the wear of the tubular furnace equipment and reducing the heat load on the second stage converter as a whole. The risk of accidents is reduced both in the tube furnace and on the entire conversion block. Based on the above, the optimal thermal mode, which is determined by the minimum temperature of the converted gas semi-finished product at the outlet of the tube furnace, is selected as

$$Q = \min X(\Gamma_i) = \min \sum_{i=1}^{n} x_i(\Gamma_i), \;\; i = 1,2, \dots , n$$

where: X is a temperature of converted gas semi-finished item on the tubular furnace output; x_i is a temperature of converted gas semi-finished item on the i-th furnace chamber output; Γ_i – fuel gas flow rate in burners of the i-th furnace chamber.

At the same time, the heat regime, which is characterized by a decrease in the temperature of the semi-finished product at the outlet of the tube furnace, leads to a decrease in the quality of the process gas. That is, to meet the third control goal, it is necessary to set a thermal mode in the tube furnace, characterized by an increase in the temperature of the semi-finished converted gas at the outlet.

The control problem such an object can be formulated as a multi-criteria dual problem. Using the decomposition method of "resource allocation" [1,2], we will proceed to the solution of a single-criteria problem with the allocation of one criterion and the main constraint.

$$\min X = \min \textstyle\sum_{i=1}^{n} x_i(\Gamma_i) \tag{1}$$
$$Y_1 \le ZY_1 \tag{2}$$
$$\underline{x_i}(G) \le x_i(\Gamma_i) \le \overline{x_i}(G) \tag{3}$$
$$\underline{\Gamma_i} \le \Gamma_i \le \overline{\Gamma_i} \tag{4}$$
$$Y_2 \le BY_2 \tag{5}$$
$$TK \le BTK \tag{6}$$
$$SN \le BSN \tag{7}$$

Restriction (2) – the main (basic) restriction.

$\overline{x_i}(G)$ – the converted gas semi-finished product temperature limit at the outlet of the i-th furnace chamber at the maximum permissible heat load on the pipes, depending on the flow rate of the SGM (raw material) vapor-gas mixture for conversion; $\underline{x_i}(G)$ – minimum permissible converted gas semi-finished product temperature at the outlet of the i-th furnace chamber at the minimum permissible thermal regime in the reaction zone, depending on the SGM consumption for conversion; $\underline{\Gamma_i}$ and $\overline{\Gamma_i}$ – lower and upper limits of fuel gas flow rate for the burners of the i-th furnace chamber, respectively; BY_2 – upper limit value for Y_2; BTK – upper limit value for TK; BSN – upper limit value for SN; Y_1 – the current value of methane concentration in converted gas at the outlet of unit conversion; Y_2 – the current value of methane concentration in the process gas at the outlet of the preparation; TK – the current temperature of the converted gas at the outlet of unit conversion; SN – the current value of the ratio of nitrogen-hydrogen in the reaction mixture.

The decomposition of problem (1) – (7) divides it into subsystems located at different levels. Moreover, constraint (2) can be formally transformed as follows:

$$\sum_{i=1}^{n} x_i(\Gamma_i) \le B$$

where B is the vector of permissible temperatures (resources).

As

$$Y_1 = kX = k\sum_{i=1}^{n} x_i(\Gamma_i)$$

$$\sum_{i=1}^{n} x_i(\Gamma_i) < \frac{1}{n} ZY_1 = B$$

where k is the proportionality factor.

Function X is additive-separable by definition (the temperature of the converted gas semi-finished product at the outlet of the first stage converter is a function of the sum of the fuel gas flow rate to the individual furnace chambers and corresponds to the sum of the converted gas temperatures in the furnace chambers). It follows that the goal function (1) and the constraint (2) are also separable. Therefore, the “resource allocation” method is the most suitable; it gives good results when constructing decomposition algorithms for solving control problems. [3] The solution of the problem (1) – (7) was carried out by selecting the permissible temperatures (resources), checking it for optimality and improvement. The parameter z_i is introduced - the amount of resources allocated for i-th furnace chamber.

$$\textstyle\sum_{i=1}^{n} z_i \le B \tag{8}$$

It is assumed that z_i is used "in the best way".

$$\omega_i = \min x_i(\Gamma_i) \qquad i = 1, \dots, n \tag{9}$$

$$x_i(\Gamma_i) = z_i \tag{10}$$

$$\underline{\Gamma_i} \le \Gamma_i \le \overline{\Gamma_i} \tag{11}$$

$$\underline{x_i}(G) \le x_i(\Gamma_i) \le \overline{x_i}(G) \tag{12}$$

where ω_i is the goal function of the i-th task.

$$Q = min \textstyle\sum_{i=1}^{n} \omega_i(z_i) \tag{13}$$

$$\textstyle\sum_{i=1}^{n} z_i \le B \tag{14}$$

$$Y_2 \le BY_2 \tag{15}$$

$$TK \le BTK \tag{16}$$

$$SN \le BSN \tag{17}$$

Thus, if $z^0 = (z_1^0, \dots, z_n^0)$ is the solution of coordinating task and Γ_i^0 is the solution of i-th subtask (9) – (12) , $\Gamma^0 = \left(\Gamma_1^0, \dots, \Gamma_n^0\right)$ – initial solution of a task.

A coordinating task is unacceptable only if the direct task does not have an acceptable solution. On the other hand, a coordinating task does not have an optimal solution only if the original problem does not have an optimal solution.

The solution of the general control problem starts with the solution of sub-tasks at fixed tasks for temperatures of the converted gas semi-finished product at the outlet of the chambers of the tubular furnace. As a result, we obtain the optimal value of temperatures, determine the maximum of them, and then, to obtain lower and more uniform temperatures, the coordinating task is solved. The coordination task and lower-level subtasks are solved on each iteration, but with jobs for temperatures that are already obtained and distributed after the next large iteration.

As a result of the decomposition application, the conversion unit controlling task is realized as obtaining and distributing values of temperature tasks depending on the possible concentration of methane in both the converted and the process gas.

Coordination complies with certain rules for obtaining and redistributing tasks for temperature of the converted gas semi-finished product at the outlets from the furnace chambers of the tube furnace, depending on the state of the whole stage of process gas preparation. Based on the technical and economic characteristics of the conversion process, a mathematical statement of the controlling the conversion unit task was developed. This was done taking into account the potential hazard of the conversion unit (this is one of the most potentially dangerous units on the ammonia synthesis unit) [3].

CONCLUSIONS

The paper analyzes the potentially dangerous technological process from the point of view of creating a control system in real time, its main features and risk factors highlighted. The control goal analysis in terms of the overall cost-effectiveness of the workshop allowed determining the priorities of the goals, as a result of which one of them is replaced by a priority regulatory restriction. Based on the other two goals – formalize the control criterion. As a result, a multi-purpose approach with conflicting control goals is reduced to a single-criterion, and a conversion unit control task is formalized as a hierarchical single-criterion optimal control task. The results of the decomposition of the overall control task allowed the transition to a hierarchical, multilevel real-time control system for this object.

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AN INTELLIGENT SYSTEM FOR CHOOSING A METHOD OF GAS PURIFICATION BASED ON FUZZY LOGIC

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ИНТЕЛЛЕКТУАЛЬНАЯ СИСТЕМА ДЛЯ ВЫБОРА МЕТОДА ОЧИСТКИ ГАЗА НА ОСНОВЕ НЕЧЕТКОЙ ЛОГИКИ

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