Modern Development Technologies and Investigation of Food Production Technological Complex Automated Systems

ABSTRACT

Nowadays, the application of modern technologies, the scenario-targeted approach namely, allows to provide the stable quality of product and energy saving in conditions of the objects changing parameters at the stage of control system development. These technologies also include the genetic algorithms and network structures. The following article presents the variants of modern technology applications at the stage of control system development of the separate departments of sugar factory, diary enterprises and brewery.

CCS Concepts

• Information systems→Process control systems

Keywords

statistical diagnostics; evaporation station; coordination; multilevel hierarchical system; technological units

1. INTRODUCTION

According to the latest trends, automation systems (AS) of complex technological units (TU) are developed in several directions, deriving from requirements such as nonstationarity, adaptability and intellectuality. Particular attention is paid to the intellectual AS (IAS), that are developed using various methods: fuzzy logic, cognitive maps, neural networks, genetic algorithms, etc [1]. The advantage of these methods is versality, that allows to apply them to objects in various industries [2-4]. Methods of linear systems, which operate in conditions of significant perturbations, continue to be investigated and improved [5]. Possibilities for using improved invariant systems have been discussed more than 70 years, although there is a problem of their combination with optimal methods [6-8].

In the process of automation of the complex objects, such as technological units, production optimization problem is formulated as a problem of top-level management. This problem is solved in relation to the limited number of state, monitoring and control variables, i.e. only those that significantly affect the progress and performance of production. In this case, the majority of technological variables are maintained at the given or optimal level by systems of automation of subsystems distinguished by specific characteristics in a technological unit [9, 10]. Control system structure is developed using decomposition methods that allow distribution of applied functions between levels ('vertically') and subsystems ('horizontally').

2. DETERMINATION OF BASIC SECTIONS AND MATERIAL FLOWS OF SUGAR FACTORY

Most of control systems installed at the factory are based on the use of local regulators, but they begin control process after occurrence of a significant mismatch that makes the control process relatively inertial. To increase efficiency of the TU, it is advisable that traditional management methods are complemented by methods of statistical diagnostics. This allows the early identification of possible problems in the technological process and algorithms of coordination, and thus enable significant reduction of regulation time and, consequently, the cost of energy and intermediate losses and increase in quality and quantity of sugar output.

Solution of coordination problem is to determine the interaction between subsystems in which control, optimal by criteria of each subsystem performance, is also optimal by general criterion for TU as a whole. Conditions of coordinability and compatibility of control subtasks are important for effectiveness of TU control

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system. These conditions guarantee solution of the general problem, if there is a solution to each of subtasks.

As an example we take technological unit of sugar factory that refers to complex objects. It has a hierarchical structure and there is a possibility of decomposition into separate subsystems interconnected by complex structural and functional relations.

The structure of TU material flows is shown in Fig. 1.

In the Fig. 1 x_i^j is input quantity vector; y_i^n is output quantity vector; U_i^m is control vector; Z_i^l is perturbation vector. Only the basic components of material flow are thereby presented.

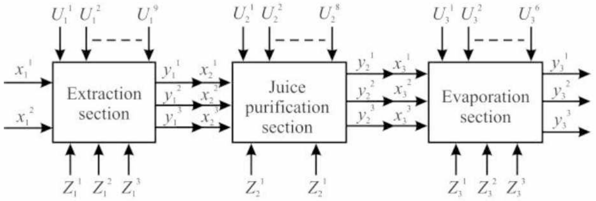

Figure 1. Structure of material flows of sugar factory TU subsystems.

In particular the work of evaporation section is characterized by an input vector, which is the output material flow from the juice purification section. The input vector x_i^n (i=2, n=1,3) is formed by consumption of II carbonation filtered juice, solid content and purity of juice. The input vector for separate evaporation section is formed as $y_2^1 = x_3^1$, $y_2^2 = x_3^2$, $y_2^3 = x_3^3$. The output values of vector y_i^n (i=3, n=1,3) are syrup consumption after the evaporation station, syrup concentration and syrup color. Control vector U_i^m (i=3, m=1,6) is formed by heating steam consumption by juice heater before evaporation station, III casing extra steam (secondary steam) consumption by heater of syrup and remelt sugar mixture, IV casing secondary steam consumption, concentrator, concentrator secondary steam consumption by condenser unit and secondary steam consumption be plant consumers. Perturbation vector Z_i^l (i=3, l=1,3) includes the following variables: heating steam temperature and heat capacity, heating steam pressure and dilution in condenser unit. Evaporation station is characterized by a large number of intermediate parameters, the main of which are: casing levels, boiling point in casings, levels in juice collectors before evaporation station, levels in ammonia water, condensate and syrup collectors, juice (syrup) concentration in casings and after concentrator, pH of syrup, etc.

3. DIAGNOSTICS OF THE TECHNOLOGICAL UNIT STATE

TU control in real time is not possible without operational optimization, because it is necessary to change not only the material and energy flows in the system, but also subsystem modes. Therefore, diagnostics of TU state is a common and binding measurement. The easiest and most common way to collect information for TU operational control tasks is taking sensor readings, results of tests conducted in factory laboratories, results of specific calculations for determining values of the technological variables and values obtained using combined methods. Problems, which can arise with this method of diagnostics, are discreteness of updating information (from 0.1 sec (time of sensor scanning by microprocessor controller) to several hours (time taken by laboratory to carry out chemical reactions)) and harmonization of obtained data for determining TU operational state. Also an important role in the speed and accuracy of diagnostics is given to the way of entry of the technological variable values, the nature of technological variable change, the nature of variable impact on technological mode as a whole and the nature of impact on technical and economic parameters.

TU control tasks have a great dimensionality caused by high dimensionality of coordinates of state, output and input variables and control actions. Mathematical model in coordinates of state is reduced to the form:

$$\begin{cases} \dot{x} = Ax + Bu + Gw \\ y = Cx + Du + Hw + v \end{cases}, \tag{1}$$

where *x*, *u*, *y*, *w*, *v* are vectors of coordinates of state, control, output variables and perturbations and noise by measuring channel, respectively. *A*, *B*, *G*, *C*, *D* and *H* are functional matrixes of the object state, control, perturbation, output by state, output by control and output by in perturbation, respectively. These mathematical models make it possible to evaluate such properties of the object as observability and controllability.

Methods of statistical diagnostics based on the analysis of time series are convenient in determining the object state. Statistical control in managing technological process is applied for the timely introduction of corrective actions and refining algorithms for coordination. Prompt diagnostic measures are provided in this case by control charts, which in addition to signal of changes in the process, evaluation of controlled variable change and frequency of such cases, are the basis for introducing corrective actions with given limitations imposed for decision-making period.

Control charts of Shewhart should be used to analyze and monitor the smooth process of certain independent variables of samples with normal law of distribution [11-13]. The feature of Shewhart charts is generating charts for the average $\overline{X}$ for the purpose of quantity control, and standard deviation charts *R* on one sheet, and their simultaneous analysis. Falling of controlled variables beyond the control limits, which are at a distance 3σ from the center line (σ is dispersion, which for this type of chart is determined by a mean moving range), and certain variations of order of points in relation to the central line on $\overline{X}$-chart combined with analysis of *R*-chart indicate the availability or lack of nonrandom deviations and the need for corrective signal.

Control limits established on control charts do not match up with limits required by the technical specifications. They are established using simple statistical calculations based on observations at the process output. The control limits are useful in obtaining information that can help to avoid:

- regulation of controlled rate of flow, temperature, etc., if necessary;
- failure in regulation, if the latter is necessary.

Level analysis of control charts of Shewhart in the I ES casing (Fig. 2) has showed that there is no falling beyond the control limits on R and X charts in normal distribution of values. This indicates that the process is statistically controlled. Thus, there is very high probability that the process in the II casing is also statistically controlled.

Fig. 3 shows the result of generating relevant Shewhart charts: there is no falling beyond the control limits on R and X charts in normal distribution of values. The results confirm previous assumptions.

Analysis of control charts can be interpreted:

- as a signal that some changes occurred in the process;

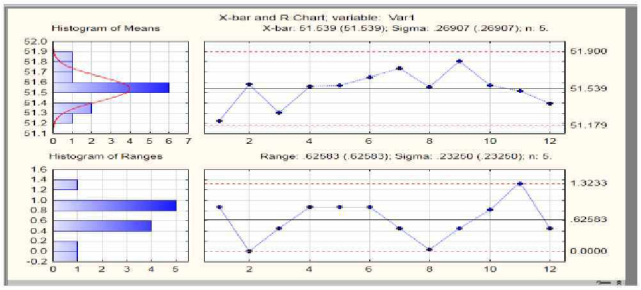

Figure 2. Control charts of Shewhart for the level in the I ES casing.

For accurate result and given technology, level analysis of the II ES casing was conducted in 16 minutes after analyzing the I casing.

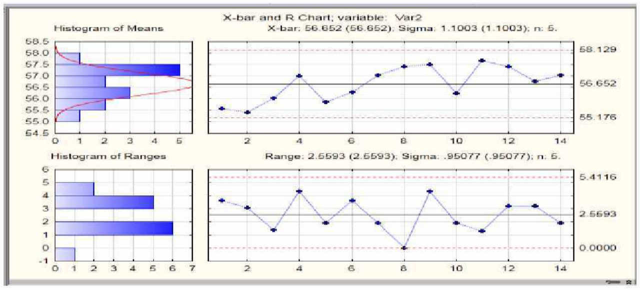

Figure. 3. Control charts for the level in the II ES casing.

- as an estimate of the variation value that needs certain corrective action to be eliminated;

- to determine the estimates of the number of such cases in the past, on the basis of which the reasons for changes occurrences are to be determined

- as a measure of product quality for periodic classification.

The logic of the interpretation of the control chart is as follows (Fig. 4): it is assumed that the study process is stable during a certain period of time while the data for analysis is being collected. This allows the use of the average based on the batch average meanings and mean range to set control limits. On the basis of the received data and calculated values, a prediction of the possible process operation is made, in particular, the boundaries of the expected variation of batch ranges and batch average meanings are determined.

Batch ranges and averages are compared to the predicted values. In the case of coherence of the observed and predicted values, it is assumed that the researched process is stable. To prove stability, it is necessary to certify its flow within the control limits during a considerable period of time. If the process does not fall within the limits, it is unstable and thus specification and elimination of the peculiar effects (non-conformity of raw materials with nominal values, displacement of the sensor scale, etc.) are required, for which relevant corrective actions are introduced.

The usage of control charts implies the introduction of corrective actions only after occurrence of the evidence of the process instability. The corresponding evidence is the emission beyond control limits or the location of points on the control charts in accordance with one or more of the eight criteria. Based on the experience of work with Shewhart charts, it is believed that the first three criteria indicate a critical discrepancy, and the rest prove a signal for the introduction of precautionary actions.

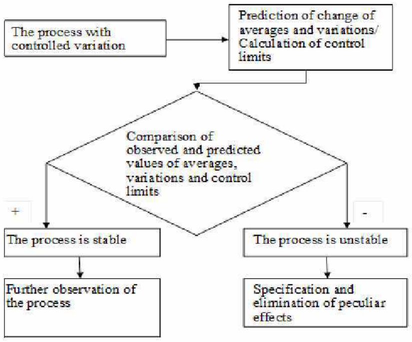

Figure 4. Algorithm for interpretation of the control charts of Shewhart.

The benefits of using control charts are as follows:

- Shewhart charts serve as "filters" for noise which occurs in any data set;

- the appearance of an emission on the chart always testifies to the fact that the process has gone wrong and it is necessary to look for a peculiar effect, regardless of the number of subgroups being investigated;

- control charts can be applied when models of technological processes or objects are unknown or approximate.

If there are emissions on the control charts (Fig. 2, Fig. 3), this will prove the possible occurrence of deviations of levels from the set value in the I and II ES casings, which is unacceptable, since in the future with a decrease in the level it can lead to: the exposure of the heating tubes of the evaporator, increase in the color of the syrup, increase in the color of the syrup and increase in the sucrose breakdown; exceeding the level triggers the following threats: intrusion of the syrup into the condensers, decrease in the intensity of heat transmission and reduction in the concentration of dry substances in the syrup. All these lead to significant energy, resource and financial losses, which is unacceptable in the current context of resource and energy efficiency of production. Maintaining an optimal level of the syrup in the evaporator ensures its maximum productivity.

In the case of falling beyond control limits on the charts it is necessary to introduce corrective actions, which, depending on their causes, may be traditional changes in refining actions, regulator settings, system structure or using coordination algorithms.

4. OPERATION COORDINATION OF MAJOR SUBSYSTEMS OF SUGAR FACTORY TU

Iterative algorithms are used in tasks related to TU subsystem coordination [14, 15]. When making operational decisions in a complex hierarchical system of a sugar plant, the main objective is to find at each level $(i=\overline{1,N})$ a vector of solutions $\overline{x}_i(t)$ that provide a maximum of the system vector of target functions $F(x_1,...,x_N)$ under a coordination task $x_{N+1}(t)$ obtained from control level (N+1). Moreover, the decision-making process is carried out discretely at moments of time $t = \overline{1,T}$ and in the general case, the sample spacing for management increases from the lower levels to the upper. A part of the solutions (mainly on the lower levels) has the nature of control actions, and the greater part only coordinates the work of subsystems on different levels. Assigning the target functions to subsystems of lower levels is also a means of coordination, whereas this task assumes that they have already been selected. The solution found $\{x_i\}, i = \overline{1,N}$ is to belong to a subset of the permissible system regimes (technological, reliable, economic, etc.), $C \subset X$ that is to be consistent with the technological capabilities.

A direct attempt to use a unique universal criterion of the top-level makes the optimization task too complicated and ignores the presence of proper target functions in the appropriate subsystems. In addition, the universal target function $F(\bar{x}_N)$ does not explicitly depend on the decisions taken by the subsystems of lower levels, which complicates the choice of subsystems operating modes and ways to improve it. Therefore, we will predict that for each j subsystem of level i, proper goals $F(\bar{x}_{ij})$ are set on the multitude of subsystems solutions, while the system target function $F(\bar{x}_1,...,\bar{x}_N)$ is vector and depends on both the universal $F(\bar{x}_N)$ criterion and the target subsystem functions $F(\bar{x}_{ij})$.

It is obvious that the task of the optimal management of the multi-stage production of a sugar plant reduces to the equivalent task of the optimal management of the individual stages, taking into account the interaction between them, which requires the creation of a multi-level hierarchical system where each of these stages is divided into separate subsystems [7].

The basis of the typical subsystem coordination task is a two-level structure, but there is always a series of non-trivial approaches which require an operational solution for a particular production and TU. It is common to study optimization issues for a two-level system and to accept this task as the main module for any system of the N-level, while the result of optimization on the level (i) is considered already set for solving the problem on the level (i-1).

Or, if $\bar{x}_N$ is written in the form of $\bar{x}_N = \{x_{ij}\}$, $i = 1,N, j = 1,M$ where $M = m_i$ is the number of subsystems on the i-level management, it is assumed that when finding solutions $x_{(i-1)j}, j = \overline{1,m_{i-1}}$, all estimates $\bar{x}_{ij}^{0}, j = \overline{1,m_i}$ are already accepted, therefore various iterative methods are mostly used for the optimization in multi-level systems.

Instead of a problem with a clear solution x_{N+1} on a (N + 1) level and a fixed number of levels N, let's consider some set of problems with N = 1,2,3 ...; $x_{N+1} = [0,\infty]$. In this case, the maximum of functions $F(\bar{x}_1,...,\bar{x}_N)$ will depend on N and x_i. Thus, the original clear task is actually blurred which leads to the concept of fuzzy solution for each level of management. This allows us to apply the apparatus of the fuzzy set theory to solve the problem.

We will use the function of the membership of approved solutions to a subset of acceptable, effective and coordinated solutions $\mu_D(\bar{x}_N)$ as a feature of the approved solutions by the individual subsystems of the sugar plant and for the system as a whole, wherein this function is not reduced to the function $F(\bar{x}_N)$ for clear solutions, since it includes not only the performance characteristics of the solution but also the characteristic of its acceptability (the degree of membership of the $\bar{x}_N$ solution in a subset of acceptable modes C) and coherence with the goals and limitations of the subsystems of lower levels (the degree of membership of the $\bar{x}_N$ solution in a subset of coordinated modes K). The membership functions are determined on the multitude of solutions $X = \{x_{ij}\}$. The efficiency of the solution is given by a fuzzy intention $G \subset X$ as a fuzzy subset with a membership function $\mu_G(x_{ij})$, the acceptability of a solution – by a fuzzy subset $C \subset X$ with a membership function $\mu_C(x_{ij})$ and co-ordination – by a fuzzy subset $K \subset X$ with a membership function $\mu_K(x_{ij})$. The resulting effect of the fuzzy intention G, the fuzzy limitation C, and the fuzzy coordination K on the choice of the solution x_{ij} may be represented by the intersection $G \cap C \cap K$. The membership function for the intersection is given by the relation

$$\begin{aligned} \mu_{G\cap C\cap K}(x_{ij}) &= \mu_G(x_{ij}) \wedge \mu_C(x_{ij}) \wedge \mu_K(x_{ij}) = \\ &= \max\{\mu_G(x_{ij}), \mu_C(x_{ij}), \mu_K(x_{ij})\}; x_{ij} \in X. \end{aligned} \tag{2}$$

Then the fuzzy subset $D = G \cap C \cap K$ will be called a fuzzy solution of the subsystem j on the level i, wherein

$$\mu_D(x_{ij}) = \mu_{G\cap C\cap K}(x_{ij}) . \tag{3}$$

In the presence of material flows within the hierarchical levels or the equations of the material balance, which describe the groups of subsystems, the solution for the subsystem j on the level (i + 1) is associated with the solution of the subsystems of the level i with help of the equation $x_{(i+1)j} = f(x_{i1},...,x_{im})$.

The work of the subsystem j on the level (i + 1) will be the most effective in case every subsystem j of the level i will make optimal decisions (maximizing its membership function), and when determining the coordination tasks for subsystems of the lower level we will strive to maximize their projection on the axis $x_{(i+1)j}$, that is

$$\mu_K(\sum_{j-1}^{M} x_{ij}) = \max_{\{x_{ij}\}}[\mu_D(x_{i1}) \otimes ... \otimes \mu_D(x_{iM})] \cdot \tag{4}$$

The application of the principle of optimality allows us to implement the most effective way of coordinating solutions which are made on the certain levels of the hierarchy [12]. This principle allows to minimize the information exchange between levels and provide local processing of information within subsystems.

The active hierarchical system of the sugar plant described this way in the language of the theory of fuzzy sets is completely defined, since the given structure of the system and the allocated levels of the hierarchy, the advantages for each subsystem are revealed by setting the corresponding membership functions, the system of equations and limitations which describe the connections within the hierarchical system.

Optimization sub-task is developed for each subsystem as a result of decomposition of a basic task consisting in the technological unit control. Coordination sub-task is solved using the principle of forecasting subsystem interactions based on iterative algorithm. The results of task solving are shown in Fig. 5.

In coordination steps 5 and 6 overall performance of TU ($\sum I_i, i = 1,3$) is higher than performance without coordination. It is typical for this example that a particular index I_2 decreases in the course of coordination.

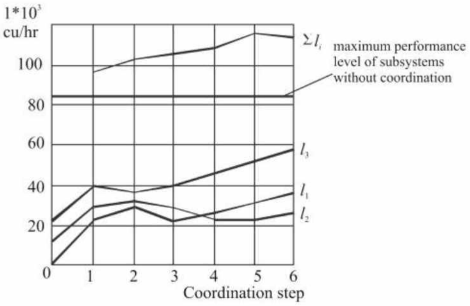

Figure 5. **Coordination of TU subsystems.**

Practical implementation of coordination algorithms should take into account that mathematical models and objective functions for each TU subsystem are functions of many variables. Often the functions are non-convex, so this complicates preliminary assessment of convergence of these algorithms. Correct formulation of basic TU control task is the main condition of using these algorithms.

5. CONCLUSIONS

The paper distinguishes sets of input and output technological variables and investigates their interactions and relationships on the basis of the proposed analysis of complex hierarchical system of sugar factory.

The proposed methods allow early detection of technological deviations in TU operation using statistical analysis and control charts of Shewhart, as well as introducing necessary corrective actions.

The basic coordination task for the TU subsystems distinguished is adjustment of material flows with restrictions on the quality of intermediate and finished products.

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7. REFERENCES

[1] Korobiichuk, I., Siumachenko, D., Smityuh, Y., Shumyhai, D. 2017. Research on automatic controllers for plants with significant delay. *Advances in Intelligent Systems and Computing*, 519. (2017), 449-457. DOI= http://doi.org/10.1007/978-3-319-46490-9_60

[2] Korobiichuk, I., Bezvesilna, O., Ilchenko, A., Shadura, V., Nowicki, M., Szewczyk, R. 2015. A Mathematical Model of the Thermo-Anemometric Flowmeter. *Sensors*, 15, (2015), 22899-22913. DOI= http://doi.org/10.3390/s150922899

[3] Karachun, V., Mel'nick, V., Korobiichuk, I., Nowicki, M., Szewczyk, R., Kobzar, S. 2015. The Additional Error of Inertial Sensor Induced by Hypersonic Flight Condition. *Sensors. 16*(3), 299. http://doi.org/10.3390/s16030299

[4] Korobiichuk, I., Shostachuk, A., Shostachuk, D., Shadura, V., Nowicki, M., Szewczyk, R. 2016. Development of the Operation Algorithm for a Automated System Assessing the High-rise Building. *Solid State Phenomena*. 251, (2016) 230-236. DOI= http://doi.org/10.4028/www.scientific.net/SSP.251.230

[5] Polyak, B.T., Khlebnikov, M.V., Shcherbakov, L.S. 2014. Linear System Control under External Perturbations: LMI Technique. *M.: LENAND*, (2014), 560.

[6] Kuntsevich, V.M. 2008. Quasi-invariance, Robustness and Adaptation in Control Systems. Scientific Seminar Works "70 Years of Invariance". Moscow, *M.: Publishing Company "LKI"*, (June 2, 2008), 256 (61-90).

[7] Korobiichuk I., Lutskaya N., Ladanyuk A., Naku S., Kachniarz M., Nowicki M., Szewczyk R. 2017. Synthesis of Optimal Robust Regulator for Food Processing Facilities. *Advances in Intelligent Systems and Computing,* 550, Automation 2017, 2017, 58-66 DOI= http://doi.org/10.1007/978-3-319-54042-9_5

[8] Ladanyuk, A.P., Vlasenko, L.O., Zaiets, N.A. 2006. System Analysis of a Complex Object in Diagnostic and Coordination Tasks. *AVP*, №2 (2006), 44-47.

[9] Klyachkin, V.N., Krasko, T.I. 2011. Chart of Effective Dispersion for Control of Dispersion in Multiparameter Process. Informatics, Modeling, Design Automation: Collection of Scientific Papers. ed. N.N Voit. Ulyanovsk: UlSTU (2011), 224-228.

[10] Kharlamenko V., Ruban S., Korobiichuk I., Petruk O. 2017. Adaptive Control of Dynamic Load in Blooming Mill with Online Estimation of Process Parameters Based on the Modified Kaczmarz Algorithm. *Advances in Intelligent Systems and Computing,* 543, 2017, 227-233 DOI= http://doi.org/10.1007/978-3-319-48923-0_28

[11] Ladanyuk, A.P., Shumygay, D.A., Boyko, R.O. 2013. Case Coordination of Nonstop Technological Unit Subsystems. *International Scientific and Technical Journal "Problems of Control and Informatics"*, №14 (2013), 117-122.

[12] Korobiichuk I., Ladanyuk A., Shumyhai D., Boyko R., Reshetiuk V., Kamiński M. 2017. How to Increase Efficiency of Automatic Control of Complex Plants by Development and Implementation of Coordination Control System. *Advances in Intelligent Systems and Computing,* 543, 2017, 189-195 DOI= http://doi.org/10.1007/978-3-319-48923-0_23

[13] Vlasenko, L.O., Ladanyuk, A.P. 2016. Control cards in the statistical analysis and synthesis methods of automated control systems. *Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine. Series: Engineering and Power Engineering of Agroindustrial Complex*, № 256 (2016), 61-68.

[14] Ladanyuk, A.P., Zaiets, N.A., Vlasenko, L.O. 2016. Modern technologies for the design of automation systems for complex objects (network structures, adaptation, diagnostics and forecasting): monograph. *K.: Lira-K*, (2016), 312.

[15] Zaiets, N.A., Shtepa V.M. 2011. Using Genetic Algorithm for Solving Optimization Problems in Electrical Engineering. *Scientific Bulletin of the National University of Life and Environmental Sciences of Ukraine. Series: Engineering and Power Engineering of Agroindustrial Complex*, № 166 (2011), 157-164.