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Multi-Criteria Equipment Control in Complex Engineering Systems

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ABSTRACT

This study illustrates the use of a compressor control system based on a fuzzy logic controller. A method for controlling the compressor based on linguistic rules and indirect methods of obtaining fuzzy conclusions was formulated. The method is based on a set of linguistic rules of fuzzy logic control using fuzzy conclusions technique which calculates the amount of control or influence compensating external disturbance. The influence of controlled information about the behaviour of complex engineering systems on the simulation of different modes of operation was studied.

Key words: Complex engineering systems operational reliability, computer-assisted management, processing equipment, complex engineering systems

INTRODUCTION

Nowadays, almost all Complex Engineering Systems (CES) comprise control and measuring devices and automatic equipment (CMD and A) that ensure protection and management of individual devices and equipment included in the CES (Sharoglazov *et al*., 2004). Refuelling stations for vehicles and gas storage tanks for households, such as Automobile Gas-Filling Compressor Stations (AGFCS), gas stations and Cryogenic Gas Filling Stations (CryoGFS) are, in turn, CESes requiring permanent operational and equipment control.

However, the dynamic characteristics are directly related to the number of vehicles that arrive at the gas station, pressure in the main pipeline, the technical condition of equipment and technical decisions taken at the design stage (control availability over processing equipment power capacity). In addition, the system is significantly influenced by the chemical composition of natural gas, mechanical impurities and humidity. It is necessary to establish rules of compensating external influences and control when changing the dynamic characteristics of the CES (Khvorov *et al*., 2013).

Parametric principles of complex engineering systems control received the most comprehensive study. Studies on this problem by Severtsev *et al*. (2013) are the most well-known (Saushev and Shoshmin, 2010; Severtsev *et al*., 2013). Thus, to control the electric drives it was proven possible to use the interrelation of the structure and parameters of the electric drive control system with expansion coefficient of the impulse response into the Laguerre series. The issue of accounting the influence of controlled information about the behavior of complex engineering systems for the simulation of different operation modes was considered in detail.

Back in the late 1980s, management principles using a qualitative correlation between the degree of opening of the valve and the refuelling time of the vehicle were proposed, i.e., management rules and knowledge. The hard-software tools used in the system are designed with the possibility of learning, for which purpose mechanisms similar to neural networks are used.

A large number of industrial and consumer systems operating now a days use the theory of fuzzy sets, fuzzy logic and fuzzy reasoning. The main works in this area were conducted in Japan. Unlike simple electronic controls systems, control systems with multi-criteria fuzzy logic are applicable most effectively in complex, difficult to formalise and poorly structured processes that can be operated by qualified operators without specific knowledge of the underlying dynamics of the operation of these processes. The most common criteria of a control system with fuzzy logic application being rational can be formulated as:

- A very complicated production process, when there is no simple mathematical model
- Non-linearity of the processes of higher order
- Necessity to process linguistically formulated rules and expert knowledge

The main idea used in control systems with fuzzy logic was formulated by its founder L. Zadeh and lies in the introduction of 'expert experience' or a Decision Maker (DM) in the development of the dynamic process control scheme. According to the creator of the theory of fuzzy logic: '...with the increasing complexity of the system gradually decreases person's ability to make accurate and at the same time, significant statements about its behavior until it reaches a threshold beyond which the accuracy and relevance become mutually exclusive characteristics...' (Terano *et al.*, 1993).

Time honored and practically used up to the present time, equipment control methods for pumping processes, compression, re-gasification, commercial accounting and energy consumption are computational tools that use Proportional-Integral-Differential (PID), adaptive, non-linear or complex (mixed) control. The main special characteristic of these methods is the minor necessity of the influence of external disturbing factors and small change or a complete determinacy of dynamic characteristics (Yevstifeev, 2014; Lugai and Yevstifeev, 2012).

The accumulated experience of domestic and foreign works in the control of aircraft, marine vessels and vehicles shows the validity and relevance of the application of control systems with controllers with non-linear and fuzzy logic.

This study illustrates the use of a control system with fuzzy logic for compressor equipment control at the gas station.

MATERIALS AND METHODS

Compressor control system using a fuzzy logic controller: Figure 1 shows a diagram of a compressor control system based on a Fuzzy Logic Controller (FLC), the instrumental part includes a microcontroller.

Control and measuring devices and analogue sensors measure rotor speed, oil temperature, the temperature of the glycol, the vibration affecting the input of the Analogue-to-Digital Converter (ADC) embedded in the microcontroller level in the form of a voltage; after converting the voltage into a digital form, deviations from the operational mode recommended in documentation are calculated. Then, on the basis of the linguistic rules of the Fuzzy Logic Control (FLCLR) using the mechanism of fuzzy conclusions, the amount of control action is calculated and supplied to the comparator via a digital-to-analogue converter. The comparator provides a control feedback with the executive mechanism consisting of a driver and a relay.

A method for controlling the compressor based on the linguistic rules and indirect methods of obtaining fuzzy conclusions: Let's denote as follows k- time moment, $e_i^{(k)} = r_i - y_i^k$- alteration of the controlled value I; $\Delta e_i^{(k)} = e_i^{(k)}$- alteration of the controlled

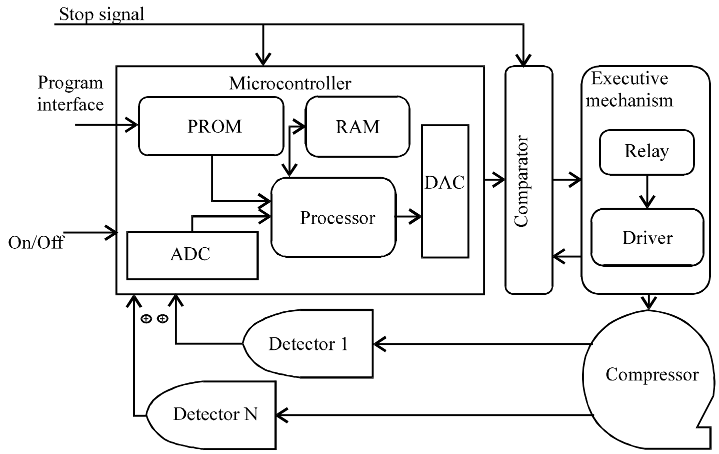

Fig. 1: Diagram of the compressor control system

first order value i; $\Delta^2 e_i^{(k)} = \Delta e_i^{(k)} - \Delta e_i^{(k-1)}$ - alteration of the controlled second order value i; $\Delta u_i^{(k)} = \Delta u_i^{(k)} - \Delta u_i^{(k-1)}$ - controlled impact value increment i.

Let us formulate linguistic rules for the controller compressor:

$$\begin{cases} e_i^{(k)} = r_i - y_i^k \subset P^i \leftrightarrow \Delta u_i^k \subset P_i^{u_1} \\ e_i^{(k)} = r_i - y_i^k \subset N^i \leftrightarrow \Delta u_i^k \subset N_i^{u_1} \\ \Delta e_i^{(k)} = e_i^{(k)} - e_i^{(k-1)} \subset P^i \leftrightarrow \Delta u_i^k \subset P_i^{u_2} \\ \Delta e_i^{(k)} = e_i^{(k)} - e_i^{(k-1)} \subset N^i \leftrightarrow \Delta u_i^k \subset N_i^{u_2} \\ \Delta^2 e_i^{(k)} = \Delta e_i^{(k)} - \Delta e_i^{(k-1)} \subset P^i \leftrightarrow \Delta u_i^k \subset P_i^{u_3} \\ \Delta^2 e_i^{(k)} = \Delta e_i^{(k)} - \Delta e_i^{(k-1)} \subset N^i \leftrightarrow \Delta u_i^k \subset N_i^{u_3} \\ e_i^{(k)} = 0 \leftrightarrow \Delta u_i^k = \varnothing \end{cases} \tag{1}$$

where, r_i is the given value of i; y_i^k is the current value of i; P_i^u is a fuzzy set with the membership function of conclusions for each variable in case of a positive increment of the regulatory impact value; N_i^u is a fuzzy set with the membership function of conclusions for each variable in case of a negative increment of the regulatory impact value.

If we assume that the detectors have a constant measurement error of the input variable, the membership functions of conclusions have the form of straight lines and the membership functions of prerequisites have the form of arc-tangents, the parameters of membership functions a_i and b_i can be defined.

If there is information from the compressor shaft speed detector, prerequisites membership function (Fig. 2a) is as follows:

$$\begin{cases} P_i(e_i) = \frac{\operatorname{arctg}(d_i e_i)}{\pi} + \frac{1}{2}, \\ N_i(e_i) = \frac{\operatorname{arctg}(-d_i e_i)}{\pi} + \frac{1}{2}, \end{cases} \tag{2}$$

where, $d_i = tg\,(0.45\pi)/a_i$, i = 1, 2, 3.

Conclusions membership function (Fig. 2b) is as follows:

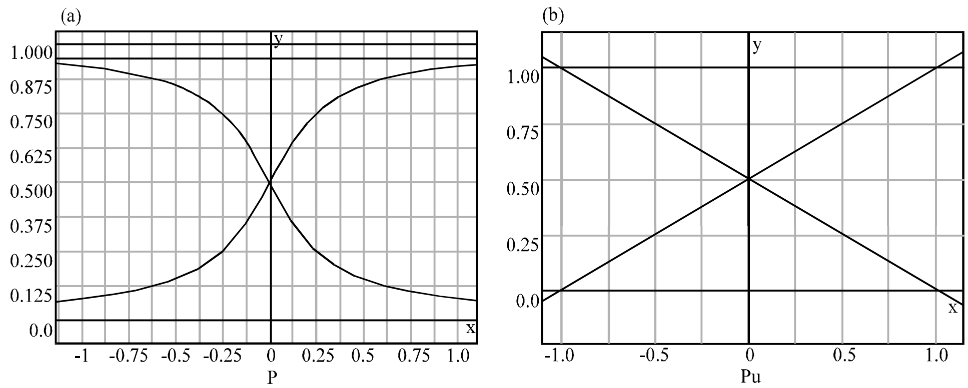

Fig. 2(a-b): Graphs of the compressor control system functions, (a) Prerequisites membership and (b) Conclusion membership

$$\begin{cases} P_{u_i}(\Delta u_i) = \frac{1}{2b_i} + \frac{1}{2}, \\ N_{u_i}(\Delta u_i) = -\frac{1}{2b_i} + \frac{1}{2}, \end{cases} \quad (3)$$

Using fuzzy conclusion procedures (Terano *et al*., 1993) a set of predetermined values is formed, thus, the intersection point of all of the membership functions can be expressed as:

$$\begin{cases} \Delta u_1 = \frac{\text{arctg}(d_1 e_k) + \text{arctg}(d_2 \Delta e_k)}{\pi(g_1 + g_2)}, \\ \Delta u_2 = \frac{\text{arctg}(d_2 \Delta e_k) + \text{arctg}(d_3 \Delta^2 e_k)}{\pi(g_2 + g_3)}, \\ \Delta u_3 = \frac{\text{arctg}(d_3 \Delta^2 e_k) + \text{arctg}(d_1 e_k)}{\pi(g_3 + g_1)}, \end{cases} \quad (4)$$

where, $g_i = 1/(2b_i)$, I = 1, 2, 3.

Impact of multiple criteria on the control based on the linguistic rules and indirect methods of obtaining fuzzy conclusions: The influence of various properties and parameters of the controlled object on the production characteristics is different. As a result, when considering a set of criteria, they must be ranked and a subsequent verification of the adequacy of the selected set of indicators must be conducted. In a number of complex technical systems there are problems of solutions perception, when the most suitable (optimal in some sense) decision is not always perceived as such. As a result, the concept of multiple criteria often leads not to the rational use of particular solutions or numerical values particular indicators but of the algorithms to find them. Therefore, in a multi-objective control system it is desirable to establish a general algorithmic decision determining the most rational relationship between individual properties and process indicators of the compressor functioning.

The decision making is defined in this study as the selection of the optimal project among several alternative projects achieving some goals. In the decision making theory the following issues are discussed: Defining a set of alternative projects, their evaluation and comparison. In addition, when making decisions has several goals, such decisions are called multi-purpose.

In particular with the complexity of the decision growing, experts and their experience in creating systems analogues become more important as well. It is especially important to define the assessment structure and criteria for the selection of alternative projects. In general, the evaluation of alternative projects is based on many criteria and indicators of the controlled object and such decisions are called multi-criteria.

Information on the indicators can be divided into numerical, qualitative and linguistic categories. All the approaches currently used to identify the evaluation structure and decision making for multi-objective control can be divided into statistical and dynamic.

If it is known that the data contains no noise and errors, it is necessary to consider all the possible data assessments, i.e., depending on the type of alternative project specified values must be represented as a possible assessment. Regression analysis is used in this case as a model.

Statistical approaches use methods based on probability approach and methods based on the theory of capabilities, e.g., when changing indicator values a probabilistic inaccuracy (noise) is added in the evaluation of alternative projects.

In order to compare the values of different indicators and criteria, it is normalised using expression:

$$f = \frac{f_{H3M} - f_{min}}{f_{max} - f_{min}} \quad (5)$$

Consequently, normalised values are substituted in the general algorithmic solution which is used in the linguistic rules (Eq. 1) and fuzzy conclusion procedures (Eq. 4) when forming sets of specifying values.

RESULTS AND DISCUSSION

Practical application results: Currently, a number of components of a unified automated system of equipment control at gas stations with multi-criteria fuzzy control have been developed. The main objective of this system is to provide adaptive control over equipment at gas stations. Thus, the compressor shaft speed control module depends on the inlet pressure in the accumulator unit, the number of operating compressors at the station, vibration level on the compressor, the inlet pressure of the natural gas in the compressor shop, etc.

The automatic compressor control is started using virtual buttons shown on the touch control panel or by software control through the entry status code in the compressor control register. The recommended installation of settings is conducted by recording information in the non-volatile memory of the microcontroller in the process of commissioning or repair work. If the shutdown button is pressed during the compressor operation, the automated rotation speed control of the rotor of the compressor is stopped, the temporary suspension of the calculation takes place, control over the system is transferred to the compressor shutdown and the automatic control unit is transferred to the initial state. The control resume is carried out in the absence of a shutdown signal or by input signal ‘On/Off ’.

The chart shows the dependence of the rotation speed of the compressor from the regulatory impact generated by the above method (Fig. 3).

The process of testing and the experimental development of a unified automated equipment control system at gas stations with multi-criteria fuzzy control, built using Eq. 1-4 is currently under way. The results were obtained for particular compressor brands, showing that application of this approach in production activities is promising and the impact on system performance is low. Bursts of dynamic characteristics are within the 50% of the allowable limit level.

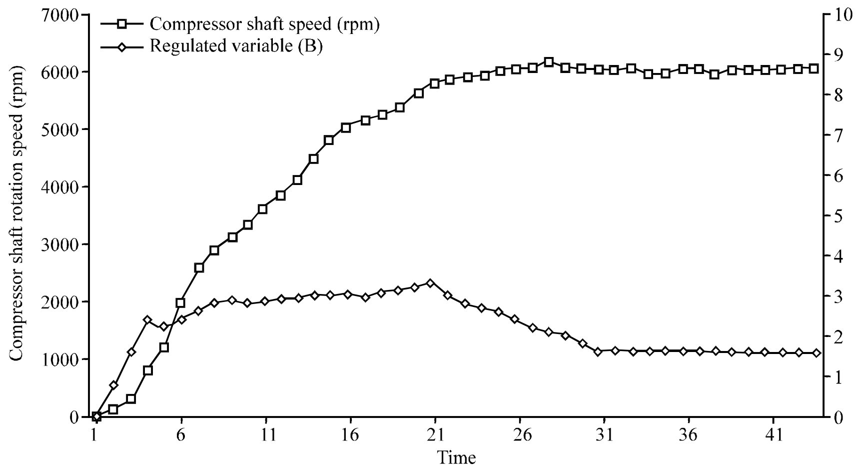

Fig. 3: Compressor shaft speed graphs and corresponding regulated variable

Linear decision-making devices are the most common in control systems. Examples of such modern works are the studies of Lu *et al.* (2013) and Dumitrescu *et al.* (2011), the non-linear functions are rarely used due to the complexity of their modelling, subsequent implementation and operation. However, modern electronics allows the implementation of a fuzzy logic control system in one case and place it in the control of complex technological systems. In this case, the self-diagnostic system and the interactive system of parameter adjustment is implemented into the composition of the non-linear system. Further development of the described approach is associated with providing the system with function of independent iterative parameter adjustment and diagnostics system.

REFERENCES

Dumitrescu, R., J. Gausemeier and C. Romaus, 2011. Towards the design of cognitive functions in self-optimizing systems exemplified by a hybrid energy storage system. Proc. Inst. Mech. Eng. I: J. Syst. Control Eng., 225: 563-575.

Khvorov, G.A., S.I. Kozlov, G.S. Akopova and A.A. Yevstifeev, 2013. Lowering losses of natural gas during transportation by main pipelines of JSC GAZPROM. Gas Ind., 12: 66-69.

Lu, Q., L. Zhang, P. Shi and H.R. Karimi, 2013. Control design for a hypersonic aircraft using a switched linear parameter-varying system approach. Proc. Inst. Mech. Eng. I: J. Syst. Control Eng., 227: 85-95.

Lugai, S.V. and A.A. Yevstifeev, 2012. Analysis of automation systems for oil and gas complex, applicable for automobile gas-filling stations. Altern. Transp., 30: 22-24.

Saushev, A.V. and V.A. Shoshmin, 2010. Modelling multi-body mechanical systems of electric drives by the method of electrical analogy. Bull. State Univ. Sea River Fleet, 4: 57-64.

Severtsev, N.A., G.A. Zelenkov and A.V. Mukhin, 2013. The dependence of the parametric safety of a complex technical systems from information. Bull. Maritime State Univ., 3: 44-46.

Sharoglazov, B.A., M.F. Ferapontov and V.V. Klementyev, 2004. Internal Combustion Engines: Theory, Modelling and Processes Calculation. SUSU Publisher, Chelyabinsk, Russia.

Terano, T., K. Asai and M. Sugeno, 1993. Fuzzy Systems Application. In: Applied Fuzzy Systems, Terano, T., K. Asai and M. Sugeno (Eds.). Academic Press, Cambridge, MA., USA., pp: 368.

Yevstifeev, A.A., 2014. Mathematical model of the process of CNG refuelling at CNG Stations. Altern. Fuel Transp., 37: 24-31.