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MODELLING BASED ON FUZZY-LOGIC CONTROL OF TECHNICAL STATE OF GAS-SUPPLY SYSTEM

The paper considers the suggested model, based on fuzzy-logic intelligent support of decision-making while realization of evaluation and forecast projects of technical state of complex gas supply system, taking into account qualitative and quantitative factors.

Key words: *gas supply system, control, managerial decision, influence factors, technical state of gas supply system.*

Introduction

One of the main strategic tasks dealing with provision of reliable gas supply on European market and home consumers is to maintain technical state of gas transporting system and to provide its further expansion. Inspection of gas –pipe lines and their facilities is necessary to determine their technical state as well as their possibilities and conditions of further functioning. Positive indices of technical state characterize safe and reliable operation of gas-pipe lines the their facilities [1]. In conditions of intensive development of gas-supply market in Ukraine the problem of reliability and efficiency of operation of gas transporting system becomes actual, aim can be achieved by permanent evaluation of its technical state, taking into account quantitative and qualitative design solutions and parameters, characterizing civil engineering and installation work as well as conditions of system operation.

Problem set-up, determining relations

Control of technical state of gas-supply system is very complex problem, requiring availability of reliable information concerning current state of engineering networks, efficient mechanisms of its processing to provide interaction of various services of gas-fuel handling facilities to keep the system in operational mode [1]. Gas-distributing system is multifactoral. Factors, influencing technical state of gas-supply system can be divided into several groups: faults, resulted in the course of system design; those, connected with civil-engineering and insulation cycle; faults, emerging in the course of operation. In [2, 3] their hierarchical classification is considered. Theory of fuzzy sets and logic, based on this theory allow describing inaccurate categories, knowledge and notions, operating them and drawing corresponding conclusions. Availability of such possibilities for formation of models, various objects, processes and phenomena on qualitative level determines the interest to organization of smart control, based on fuzzy logic methods application [4, 5]. One of the characteristic features of gas –supply is high degree of uncertainty change of large amount of influencing factors with permanently varying parameters of its functioning. That is why, development of the model of integrated evaluation of gas-supply system technical state, taking into account the uncertainty in order to improve the efficiency of control processes is the aim of the given paper.

One of the reasons of low energy saving resource in gas-supply system is the absence of reliable complex tool for control of its technical state and management of system components and processes, where factors of qualitative and quantitative character, would be taken into account. The solution of this problem is possible, applying the mathematical model of decision-making, developed on the basis of fuzzy logic theory and linguistic variables, permitting to take into account qualitative and quantative parameters, influencing the reliability of gas-supply system management [6, 7].

Fuzzy systems of control are efficiently used in spheres, where the object of control is rather complex for its accurate description and there exist stages of apriory information, regarding the system. Gas-supply system is such an object. Fuzzy systems of management have knowledge base and elements of artificial intelligence and can be realized by special fuzzy controllers, where fuzzy conclusions are performed by means of computation characteristic values of initial linguistic variable via characteristic values of input linguistic variables by logic formula, using logic operators “AND” and “OR”.

Modeling of technical state of gas-supply system control is considered on the example of influencing factors, referred to the sphere of civil – engineering and installation. Studying this process on systemic level, linguistic variable, that described civil-engineering and insulation works, cam be presented by the expression

$$Y = f_y(y_1; y_2; y_3; y_4), \tag{1}$$

where y_1 – is LV "mechanical transport damage"; y_2 –is LV "quality of welded joints"; y_3 – is LV "state of corrosion-resistant, insulation coating"; y_4 – is LV "formation of mounting stress"

Equation (1) contains variables y_2, y_3 ,which, in their turn, depend on the factors:

$$y_2 = f_{y_2}(c_1; c_2; c_3), \tag{2}$$

$$y_3 = f_{y_3}(d_1; d_2), \tag{3}$$

where c_1 – is LV "cracks of any dimensions and directions"; c_2 –LV "leaky welded joints"; c_3 – LV "gas pores and slagging of welded joint"; d_1 –is LV "violation of technology while preparation and application of insulation coating "; d_2 – is LV "poor quality of preparation of gas-pipe line bed".

Evaluation of levels of linguistic variables, that connect civil-engineering and insulation works (*Y*) with mechanical transport damage (y_1), quality of welded joints (y_2), with corrosion-resistant insulation coating state (y_3) and formation of mounting stress (y_4), is carried out, using term-sets evaluation systems, presented in Table 1.

Table 1

Influencing factors as linguistic variables

Designation and name of variables	Universal set	Terms for evaluation
y_1 – mechanical transport damage	0...100%	present, partly missing, missing
c_1 – cracks of any dimensions and directions	0...100%	present, partly missing, missing
c_2 – leaky welded joints	0...100%	present, partly missing, missing
c_3 – gas pores and slagging of welded joint	0...100%	present, partly missing, missing
d_1 – violation of the technology while preparation and application of insulation coating	(1...3) y. o.	possible, partly, impossible
d_2 – poor quality of preparation of gas-pipe line bed	(1...3) y. o.	possible, partly, impossible
y_4 – formation of mounting stress	0...100 Nm	high, average, low

Mathematical model is presented by the system of fuzzy logic equations, characterizing the surface of variable membership by corresponding term [4, 5]:

$$\mu_{\text{Н}}(Y) = \mu_{\text{П}}(y_1) \wedge \mu_{\text{Н}}(y_2) \wedge \mu_{\text{Н}}(y_3) \wedge \mu_{\text{В}}(y_4) \vee \mu_{\text{П}}(y_1) \wedge \mu_{\text{нС}}(y_2) \wedge \mu_{\text{Н}}(y_3) \wedge \mu_{\text{В}}(y_4); \tag{4}$$

$$\mu_{\text{нС}}(Y) = \mu_{\text{П}}(y_1) \wedge \mu_{\text{Н}}(y_2) \wedge \mu_{\text{нС}}(y_3) \wedge \mu_{\text{С}}(y_4) \vee \mu_{\text{П}}(y_1) \wedge$$
$$\wedge \mu_{\text{нС}}(y_2) \wedge \mu_{\text{нС}}(y_3) \wedge \mu_{\text{С}}(y_4) \vee \mu_{\text{чВд}}(y_1) \wedge \mu_{\text{Н}}(y_2) \wedge \mu_{\text{нС}}(y_3) \wedge \mu_{\text{В}}(y_4); \tag{5}$$

$$\mu_{\text{С}}(Y) = \mu_{\text{чВд}}(y_1) \wedge \mu_{\text{С}}(y_2) \wedge \mu_{\text{С}}(y_3) \wedge \mu_{\text{М}}(y_4) \vee \mu_{\text{Вд}}(y_1) \wedge$$
$$\wedge \mu_{\text{С}}(y_2) \wedge \mu_{\text{С}}(y_3) \wedge \mu_{\text{В}}(y_4) \vee \mu_{\text{П}}(y_1) \wedge \mu_{\text{С}}(y_2) \wedge \mu_{\text{С}}(y_3) \wedge \mu_{\text{М}}(y_4); \tag{6}$$

$$\mu_{\text{вС}}(Y) = \mu_{\text{Вд}}(y_1) \wedge \mu_{\text{С}}(y_2) \wedge \mu_{\text{С}}(y_3) \wedge \mu_{\text{М}}(y_4) \vee \mu_{\text{чВд}}(y_1) \wedge$$
$$\wedge \mu_{\text{вС}}(y_2) \wedge \mu_{\text{вС}}(y_3) \wedge \mu_{\text{М}}(y_4) \vee \mu_{\text{В}}(y_1) \wedge \mu_{\text{вС}}(y_2) \wedge \mu_{\text{вС}}(y_3) \wedge \mu_{\text{С}}(y_4); \tag{7}$$

$$\mu_{\text{В}}(Y) = \mu_{\text{Вд}}(y_1) \wedge \mu_{\text{вС}}(y_2) \wedge \mu_{\text{В}}(y_3) \wedge \mu_{\text{М}}(y_4) \vee \mu_{\text{Вд}}(y_1) \wedge \mu_{\text{В}}(y_2) \wedge \mu_{\text{В}}(y_3) \wedge \mu_{\text{М}}(y_4). \tag{8}$$

Usage of fuzzy logic equations provides determination of membership function $\mu_m(u)$ of all fuzzy terms. Construction of membership function provides phasing of fuzzy evaluations of influencing factors, that comprises selection of fuzzy terms (Table 1). Then we compose matrix, that reflect pair comparisons of different values of influencing factors from the point of view of their proximity to the terms, as a result we obtain the degrees of evaluation terms membership. The obtained results of membership functions we normalize by unit, dividing into the greatest degree of membership .Membership functions for linguistic variables, which describe civil-engineering and mounting works of gas-supply system are shown in Fig. 1. Membership functions cannot be used, if input variable constantly changes. Input variable can take not only u_i ($i=\overline{1,5}$), values, but also intermediate ones. Usage of linear interpolation allows to neglect this restriction. If it is known, that $\mu_m(u_i) = \mu_i$ *ma* $\mu_m(u_{i+1}) = \mu_{i+1}$, then the value $\mu_m(u^*)$, where $u^* \in (U_i, U_{i+1})$, is found from the relation [4, 5]:

$$\mu_m(u^*) = \frac{u^*(\mu_{i+1} - \mu_i) + \mu_i(u_{i+1} - u_i) - u_i(\mu_{i+1} - \mu_i)}{u_{i+1} - u_i}. \tag{9}$$

The analysis of variables (y_1, y_2, y_3, y_4) only on discrete universal set does not allow to take into account case, when mixed factors influence the design solutions. To avoid this restriction we assign as variable determination area conventional interval, where each element of the set is corresponded by certain values. Using membership functions (Fig. 1) and formula (9) we find analytical model of membership functions for evaluation of input variables for all terms, described by equations system of the form

$$\mu_m(u^*) = \frac{au^* + b}{c}, \tag{10}$$

where $a = \mu_{i+1} - \mu_i$; $b = \mu_i (u_{i+1} - u_i) - u_i(\mu_{i+1} - \mu_i)$; $c = u_{i+1} - u_i$.

To pass from obtained fuzzy sets to quantitative evaluation, it is necessary to perform the procedure of dephasing, i.e., conversion of fuzzy information into definite information. Among various methods of dephasing the most widely spread method is finding of “weight centre” of flat figure, that is why restricted membership function of fuzzy set and horizontal coordinate [4, 5]. Dephasing of fuzzy set by the principle of “weight center” gives quantitative evaluation of gas supply system technical state C_R* at set values of influencing factors

$$Y^* = (y_1, y_2, y_3, y_4) = \frac{\sum_{i=1}^{l} Y^{d_i} \cdot \mu_{d_i}(Y)}{\sum_{i=1}^{l} \mu_{d_i}(Y)}, \tag{11}$$

where l – is the number of fuzzy terms for variable evaluation Y; d_i – is the name of i-th term, $i = \overline{1,l}$; $\mu_{qi}(Y)$ – is membership degree Y to termd_i.

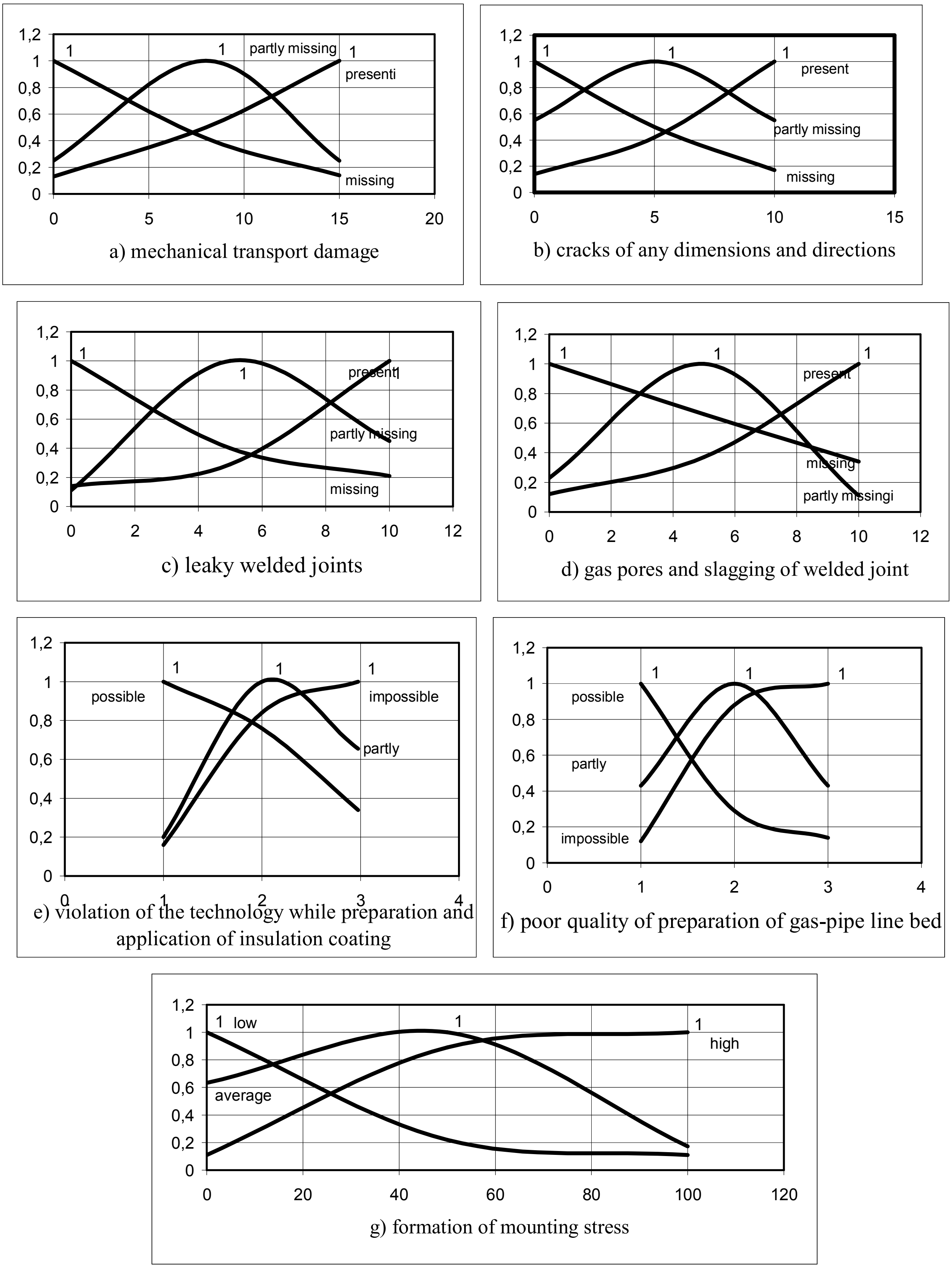

Fig. 1.Membership functions for linguistic variables , describing civil engineering works.

Using analytical formulas (4) – (8) and value of membership functions variables y_1, y_2, y_3 та y_4 (Fig. 1) we obtain the value of membership function of term-evaluation variable Y:

$$\mu_H(Y) = 0{,}64 \cdot 0{,}42 \cdot 0{,}76 \cdot 0{,}12 \vee 0{,}64 \cdot 0{,}66 \cdot 0{,}76 \cdot 0{,}12 = 0{,}76 \cdot 0{,}76 = 0{,}76;$$

$$\mu_{нС}(Y) = 0{,}64 \cdot 0{,}42 \cdot 0{,}84 \cdot 0{,}64 \vee 0{,}64 \cdot 0{,}66 \cdot 0{,}84 \cdot 0{,}64 \vee 0{,}84 \cdot 0{,}42 \cdot 0{,}84 \cdot 0{,}12 = 0{,}84 \cdot 0{,}84 \cdot 0{,}84 = 0{,}84;$$

$\mu_C(Y) = 0{,}84 \cdot 1 \cdot 0{,}84 \cdot 0{,}99 \vee 0{,}35 \cdot 1 \cdot 0{,}88 \cdot 0{,}12 \vee 0{,}64 \cdot 1 \cdot 0{,}84 \cdot 0{,}99 = 1 \cdot 1 \cdot 1 = 1$;

$\mu_{вC}(Y) = 0{,}35 \cdot 1 \cdot 0{,}88 \cdot 0{,}99 \vee 0{,}84 \cdot 1 \cdot 1 \cdot 0{,}99 \vee 0{,}35 \cdot 1 \cdot 1 \cdot 0{,}64 = 1 \cdot 1 \cdot 1 = 1$;

$\mu_B(Y) = 0{,}35 \cdot 1 \cdot 0{,}84 \cdot 0{,}99 \vee 0{,}35 \cdot 0{,}66 \cdot 0{,}84 \cdot 0{,}99 = 1 \cdot 0{,}99 = 0{,}99$.

The obtained values of membership function of variable Y allow, together with the values of membership function of variables X – design decisions and Z – operation of the system, to obtain the forecast evaluation of gas-supply system technical state. The obtained decision will be based on the results of virtual experiment, carried out using data base.

Conclusions

1. The suggested model serves the design-managers for evaluation technical state of gas-supply system as a tool for intelligent support for intended managerial decision-making, taking into account qualitative and quantitative stimulating factors, influencing the reliability of gas-distributive system.

2. On the basis of forecasting characteristics of gas-supply system technical state, obtained by means of fuzzy logic theory and linguistic variables, organizational-technical measures aimed at improvement and reconstruction of the system are developed, these measures will contribute to the increase of reliability of consumers gas-supply.

REFERENCES

1. Сідак В. С. / Інноваційні технології в діагностиці та експлуатації систем газопостачання / В. С. Сідак. – Харків: ХНАМГ, 2005. – 227 с.

2. Ратушняк Г. С. / Моделювання процесу інтелектуальної підтримки прийняття рішення щодо оцінки стану системи газопостачання методом парних порівнянь / Г. С. Ратушняк, О. І. Ободянська // Інформаційні технології та комп'ютерна інженерія. – 2010. – № 1 (17). – с. 52 – 55.

3. Ратушняк Г. С. / Моделювання надійності систем газопостачання на основі лінгвістичної інформації / Г. С. Ратушняк, О. І. Ободянська // Сучасні технології, матеріали і конструкції в будівництві. – 2009. – № 1. – с. 97 – 103.

4. Митюшкин Ю. И. Soft Computing: идентификация закономерностей нечеткими базами знаний / Ю. И. Митюшкин, Б. И. Мокин, А. П. Ротштейн. – Вінниця.: УНІВЕРСУМ-Вінниця, 2002. – 145 с.

5. Ротштейн А. П. Интеллектуальные технологии индентификации. Нечеткие множества, генетические алгоритмы, нейронные сети / А. П. Ротштейн. – Вінниця: УНІВЕРСУМ-Вінниця, 1999. – 320 с.

6. Ратушняк Г. С. / Модель багатофакторної оцінки технічного стану системи газопостачання / Г. С. Ратушняк, О. І. Ободянська // Сучасні технології, матеріали і конструкції в будівництві. – 2010. – № 1. – с. 125 – 131.

7. Ратушняк Г. С. / Розроблення моделі оцінювання технічного стану розподільчих газопроводів для створення муніципальної гіс підсистеми газопостачання / Г. С. Ратушняк, О. І. Ободянська // Національне картографування: стан, проблеми та перспективи розвитку. Київ. – 2010. – № 4. – с. 234 – 237.

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