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PROMPT MANAGEMENT ON THE BASIS OF THE DISTURBED STATE OF THE URBAN GAS SUPPLY SYSTEM

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Statement of the problem. The problem of the regulation of gas flows in urban gas distribution systems by managing them promptly is addressed.
Results. A complete mathematical model is developed of the disturbed state of a distribution gas supply system in the field of a reverse analysis which formalizes the synthesis of the throttle characteristics of the system and includes a model of the disturbed system state and the system of normal equations. Based on the synthesized throttle characteristics the algorithm was proposed of a preliminary and accurate forecast of consumption in the system.
Conclusions. The throttle characteristics of the system obtained by means of modelling are the basis of forecasts of gas consumption of domestic, municipal and industrial consumers on the basis of the principles of energy reduction.

Keywords: gas supply, operational management, analysis of flow distribution.

Introduction

The state of a gas supply system can be determined using a vector of state parameters Z that includes the dependent Y and independent X variables.

Y contains the following:

— a vector of the expenses of the environment in the areas Q with the components $Q_i(i\in \{I\}$ is a total number of areas in the system);

— a vector of node pressures P with the components $P_j(j \in \{J\}$ is a total number of nodes);

— a vector $\hat{P}_j(j \in \{J_н\}$ is a total number of energy nodes (EN) with a fixed node pressure);

— a vector of a node supply (inflow) q with the components $\hat{q}_j (j \in \{J_q\}$ is a total number of EN with a fixed node supply (inflow) including a zero supply, $\{J_н \cup J_q\} \subset \{J_z\}$ where $\{J_z\}$ is a total number of EN);

— a vector S with the components $S_i (i \in \{I_D\}$ is a total number of areas with throttle elements, S_i is a coefficient of hydraulic resistance).

A variable X contains the following:

— a vector S with components $S_i(i \in \{I_S\}$ is a total number of areas including those with throttles, $\{J_S \cup J_D\} \subset \{J\}$);

— vectors D, L with components D_i, L_i (diameters and lengths of main pipes) $i \in \{I\}$, etc.

The components of the vector X is included in what is called a single-valuedness condition [2—6, 11, 13]. In order to identify the initial vector Y a model of flow distribution is essential $U(Z) = U(Y, X) = 0$.

1. Designing a flow distribution model based on the excited state of a gas supply system. A flow distribution model [1, 2] is depicted using a ninary structural graph in its excited state containing the specified area and users' subsystems. Modelling management in the system is suggested to be conducted using predictions of gas supply levels. The reverse analysis is a synthesis of throttle characteristics. It is designed using a square matrix MBC with unknown values S_i, ($i \in \{I_D\}$). In order to determine S_i, ($i \in \{I_D\}$), it is necessary to specify how a target product is consumed, in particular gas [14—21]. This makes it imperative to identify linearly independent connections that are excessive in relation to those form the structure of a model of the excited state of a system. The model of the excited state is obtained as a result of variation which uses the principle of least action for a gas supply network [2, 5, 8, 10, 12], i.e. there is always a clear-cut connection between the vectors Y and X. An extra connection is found in early regression analysis [5, 6, 7] which is determined using the method of least squares (MLS).

A gas distribution system has different complex interior connections [3]. The configuration of MLS for a gas supply system is adjusted to the energy and mass exchange with the environment using a set J_z of energy nodes. There is no question of the original information as it does not have to do with measuring devices and their errors, i.e. such independent variables as previously specified values of the expenses of fictional lines (Q_j^{fa}, $j \in \{J_н\}$) are values changing in time and influenced by subjective factors.

It is known that MLS is designed using minimization of the residual function F, here for a set $J_н$ of the components of the vectors P and Q that are connected with a dependence by means of the Bernoulli's equation. Considering that, let us present an objective function for a hydraulic system based on the method of least squares:

$$F = \sum_{j \in J_н} \left[S_j^f \left(Q_j^{fa} \right)^{\alpha} - S_j^f \left(Q_j^f \right)^{\alpha} \right]^2 + \lambda \left(\sum_{j \in J_\eta} Q_j^{fa} - \sum_{j \in J_\pi} Q_j^{fa} \right), \quad (1)$$

where Q_j^{fa}, Q_j^f are previously specified and actual values of the gas expenses through a fictional area j; λ is the Lagrange multiplier; $\{J_\pi\}, \{J_\eta\}$ is a set of sources and outflows of a gas distribution system respectively. The second group of summands (1) confirms the hydraulics theory which runs that F should be identified as part of the continuity conditions of the environment. A system of normal pressures is designed using the minimum conditions of an objective function:

$$\frac{\partial F}{\partial Q_j^{fa}} = 2\left[S_j^f \left(Q_j^{fa} \right)^{\alpha} - S_j^f \left(Q_j^f \right)^{\alpha} \right] \times \left[\alpha S_j^f \left(Q_j^{fa} \right)^{\alpha - 1} \right] + \lambda = 0, j \in \{J_н\}. \quad (2)$$

The actual expenses Q_j^f are not independent within previous prediction as they are connected with a flow distribution model.

The exclusion λ results in a system of normal equations that meet the condition

$$\left(S_j^f \right)^2 \left(Q_j^{fa} \right)^{\alpha - 1} \left[\left(Q_j^{fa} \right)^{\alpha} - \left(Q_j^f \right)^{\alpha} \right] = idem, j \in \{J_н\}. \quad (3)$$

According to (2), (3), the specific number of extra independent connections per unit is less than of energy node flows, i.e. $J_н - 1$.

2. Synthesis of throttle characteristics of a gas distribution system. A complete mathematical model of the excited state of a gas distribution system in the range of reverse analysis that formalizes the synthesis of the throttle characteristics of the system and includes MBC [2, 4] and the system of normal equations are in the matrix form below:

$$\left\| C^r \middle| C_D^r \middle| C^f \right\| \left\| \begin{array}{c} R_{(d)}^r \\ \hline R_{D(d)}^r \\ \hline R_{(d)}^f \end{array} \right\| \left\| \begin{array}{c} Q^r \\ \hline Q_D^r \\ \hline Q^f \end{array} \right\| = \left\| M^T \right\| \left\| \bar{P} \right\|; \quad (4)$$

$$\left\| K \right\| \left\| \begin{array}{c} R_{(d)}^r \\ \hline R_{D(d)}^r \end{array} \right\| \left\| \begin{array}{c} Q^r \\ \hline Q_D^r \end{array} \right\| = \left\| 0 \right\|; \quad (5)$$

$$\left\| A^r \middle| A_D^r \middle| A^f \right\| \left\| \begin{array}{c} Q^r \\ \hline Q_D^r \\ \hline Q^f \end{array} \right\| = \left\| \bar{q} \right\|; \quad (6)$$

$$\left\|E^{f}\right\|\left\|\Theta_{(d)}^{f}\right\|\left\|Q^{f}\right\|=\left\|E^{f}\right\|\left\|\Delta_{(d)}^{f}\right\|, \quad (7)$$

where $R_j^r = S_j^r\left(Q_j^r\right)^{\alpha-1}$; $R_j^f = S_j^f\left(Q_j^f\right)^{\alpha-1}$; $\Theta_j^f = \left(S_j^f\right)^2\left(Q_j^{fa}Q_j^f\right)^{\alpha-1}$; $\Delta_j^f = \left(S_j^f\right)^2\left(Q_j^{fa}\right)^{2\alpha-1}$; $\|C\|$, $\|K\|$, $\|A\|$ are topological matrices of adhesive, contour and node elements per unit respectively; α is the indicator of the degree in the Darcy Weisbach formula; $\bar{P}$, $\bar{q}$ are fixed node pressures and a selection (including the zero one); *T* is a transportation property; the uppercase indices *r* and *f* correspond with actual and fictional network structures; the lower case index (*d*) belongs to the elements of a diagonal matrix.

From MBC we have a block with the lowercase index *D* with the size of a square matrix (4)—(6) $I\times\left(I+I_D\right)$.

A unit matrix $\left\|E^f\right\|$ contains two unit elements with the opposite signs in each line, the number of columns is the same as that of fictional areas, the number of lines per unit is smaller due to the condition (3), i.e. its size is $\left(J_н-1\right)\times J_н$.

The size of the combined square matrix (4) and (7) is $\left(I+I_D\right)\times\left(I+J_н-1\right)$.

and is specific, the number of areas with throttles precisely corresponds with the number without a unit of energy node outflows (Fig. 1).

For linearization of a nonlinear model (4)—(7) the Newton's method can be employed. A corresponding linear model of a flow distribution is below:

$$\left\|C^r\middle|C_D^r\middle|C^f\right\|\left\{\left\|\begin{matrix}\alpha\Delta P_{(d)}^r\\ \hline \alpha\Delta P_{D(d)}^r\\ \hline \alpha\Delta P_{(d)}^f\end{matrix}\right\|\left\|\begin{matrix}\partial\overline{Q^r}\\ \hline \partial\overline{Q_D^r}\\ \hline \partial\overline{Q^f}\end{matrix}\right\|+\left\|\begin{matrix}\Delta P_{(d)}^r\\ \hline \Delta P_{D(d)}^r\\ \hline \Delta P_{(d)}^f\end{matrix}\right\|\left\|\begin{matrix}0\\ \hline \delta\overline{S_D^r}\\ \hline 0\end{matrix}\right\|\right\}=\|0\|; \quad (8)$$

$$\|K\|\left\{\left\|\begin{matrix}\alpha\Delta D_{(d)}^r\\ \hline \alpha\Delta D_{D(d)}^r\end{matrix}\right\|\left\|\begin{matrix}\delta\overline{Q^r}\\ \hline \delta\overline{Q_D^r}\end{matrix}\right\|+\left\|\begin{matrix}\Delta D_{(d)}^r\\ \hline \Delta D_{D(d)}^r\end{matrix}\right\|\left\|\begin{matrix}0\\ \hline \delta\overline{S_D^r}\end{matrix}\right\|\right\}=\|0\|; \quad (9)$$

$$\left\|A^r\middle|A_D^r\middle|A^f\right\|\left\|\begin{matrix}Q_{(d)}^r\\ \hline Q_{D(d)}^r\\ \hline Q_{(d)}^f\end{matrix}\right\|\left\|\begin{matrix}\delta\overline{Q^r}\\ \hline \delta\overline{Q_D^r}\\ \hline \delta\overline{Q^f}\end{matrix}\right\|=\|0\|; \quad (10)$$

$$\left\|E^f\right\|\left\|\Psi_{(d)}^f\right\|\left\|\delta\overline{Q^f}\right\|=\left\|E^f\right\|\left\|\Phi_{(d)}^f\right\|, \quad (11)$$

where

$$\psi_j^f = \alpha \left(S_j^f\right)^2 \left(Q_j^{fa}\right)^{\alpha-1} \left(Q_j^f\right)^{\alpha};$$

$$\Phi_j^f = \left(S_j^f\right)^2 Q_j^{fa} \left\{ \left(Q_j^{fa}\right)^{2(\alpha-1)} \left[1+(2\alpha-1)\delta\overline{Q}_j^{fa}\right] - \left(Q_j^f\right)^{\alpha} \left[1+(\alpha-1)\delta\overline{Q}_j^{fa}\right] \right\}.$$

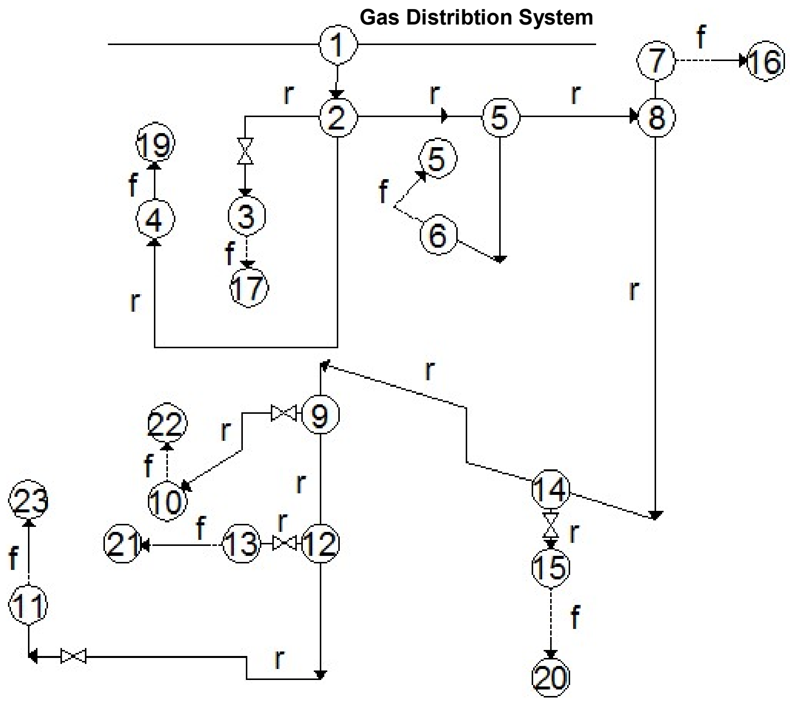

Fig. 1. Binary structural graph of an urban gas supply system of the medium (high) pressure stage: *r*, *f* are actual and fictional areas respectively

For the analysis of the mechanism of throttle characteristics, it is suggested that the results of a calculation experiment to model a flow distribution in the range of reverse analysis for a gas supply system of the medium pressure stage of a residential area are used (see Fig. 1) supplied with seven controlled throttles fitted on the branches of the energy node outflows. The prediction of the expense is made with eight previously specified vlaues Q_j^{fa} with a considerable range of changes. Modelling was performed for two options for preliminary settings of the throttles with the total capacity of the system 3350 and 24985 m^3/h at constant pressures in the energy nodes: $P_1 = 0.5$ MPa (power node) and $P_{16} = P_{17} = P_{18} = P_{19} = P_{20} = P_{21} = P_{22} = P_{23} = 0.1$ MPa (atmospheric pressure). The calculation experiment containing 17 specified options allowed 7 throttle characteristics to be synthesized (Fig. 2) in the relative coordinates

$$\overline{Q}_{Di}^{(k)} = \frac{Q_{Di}^{(k)}}{Q_{Di}^{(0)}}; \quad \overline{S}_{Di}^{(k)} = \frac{S_{Di}^{(k)}}{S_{Di}^{(0)}},$$

with a dispersion not over 3,5 % where $Q_{Di}^{(0)}$, $S_{Di}^{(0)}$ are initial properties corresponding with a zero iteration [2].

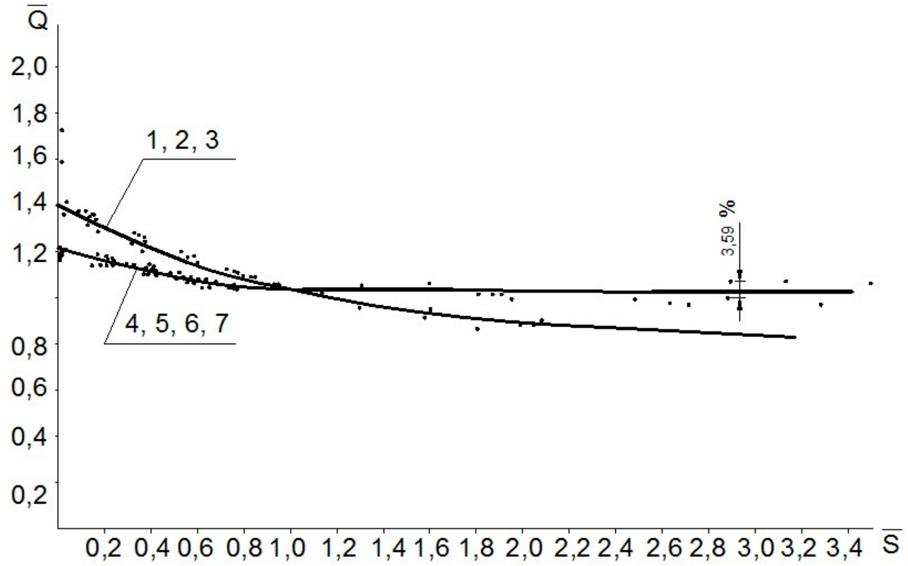

Fig. 2. Throttle characteristics of a gas supply system in the relative coordinates:
1, 2, 3 for the throttles in the areas 2—4, 2—3, 5—6 respectively;
4, 5, 6, 7 for the throttles in the areas 9—10, 12—13, 12—11, 14—15 respectively

The solution of the reverse analysis is obtained for the following restrictions if

$$S_{Di}^{(k)} \le S_{Di}^{0}, \quad S_{Di}^{(k)} = S_{Di}^{0},$$

where S_{Di}^{0} is a resistance coefficient of a throttle as it is completely open. Note that variation of the throttle characteristics is not determined with error of the measuring devices but with a methodological (residual) error in the method of least squares. An important general result of the study is no variation of the throttle characteristics to the values of Q_j^{fa} specified by the user, preliminary settings of the throttles, pressure in the source, interaction of the throttles, etc.

The throttle characteristics of a system are fundamental to predicting the gas consumption by households and industries with a transition from EN-*j* to individual users connected to this energy nodes an be designed based on the principle of energy equivalence [2—6]. Large linearity of the objective function (3) poses a certain challenge that involves chnages in the number of iteration. The number of iterations during the experiment was within $(0.5 - 50) \times 10^3$. Based on that, the algorithm of prelimiary and precise prediction can be set forth. Preliminarily it is performed using a range of changes Q_j^{fa} specified by the user and comprises modelling of flow distribution using the iteration solution of the system of equations (4)—(7), designing the throttle characteristics using the results of the calculations.

A precise analysis implements all of the characteristics and involves specification of the variables S_{Dj} borrowed from the above characteristics and included in the flow distribution data base (4)—(6) and the direct analysis.

Conclusions

1. There are plans to develop energy nodes using gas distribution systems to improve throttle characteristics that are the only suitable data to control a system with *N* remotely controlled throttles.
2. Energy-powered valves with an optical and fibre connection, shutters with the interior (operating) characteristics that recreates the configuration of throttle characteristics of a system should be employed as throttles.

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