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Kursk State Technical University
Ph. D. in Engineering, Lecturer of Dept. of Heat and Gas Supply and Ventilation
O. A. Gnezdilova
Russia, Kursk, tel.: (4712)52-38-14; e-mail: tgv-kstu6@yandex.ru

Voronezh State University of Architecture and Civil Engineering
D. Sc. in Physics and Mathematics, Prof. of Dept. of Higher Mathematics
A. A. Sedaev
Russia, Voronezh, tel.:(473)277-40-06; e-mail: vestnik_vgasu@mail.ru

O. A. Gnezdilova, A. A. Sedaev

THE BASES OF MODELLING OF THE PROCESS OF MANAGEMENT OF GAS SUPPLY CITY SYSTEMS OF MIDDLE AND HIGH PRESSURE

Problem statement. It is now of fundamental importance to make corrections to a mathematical model that accounts for a new element emerging in a management system — throttle remotely controlled from a digital centre. The aim of the paper is to perform the analysis of operative management of gas supply system functioning.
Results and conclusions. The analysis of operative management of functioning of gas supply systems on the basis of the disturbance regulation principle is performed. Technique of development of the mathematical model with the use of block matrix form of designation of the system of equations with the subsequent transaction to the algorithmic form is proposed.

Keywords: hydraulic resistance, gas pressure and consumption, a principle of perturbation regulation.

Introduction

Urban low and high pressure distribution pipelines are designed as a single network with appropriate economic considerations made. For cities and towns the structure of pipe networks is accepted to be combined with ring-jointing of major transit flows and terminal system of branches to individual users or groups of similar users. For towns, urban and rural settlements a network having all stages of pressure can be designed to be a terminal one. It is now of fundamental importance to make corrections to a mathematical model that accounts for a new element emerging in a management system, which is a throttle remotely controlled from a digital centre (CT) and which can function as a discharge regulator.

1. A model of a management system of a medium (high) stage of pressure

Using the example of a system of medium (high) stage of pressure (Fig. 1) let us discuss what corrections are to be made to the management system.

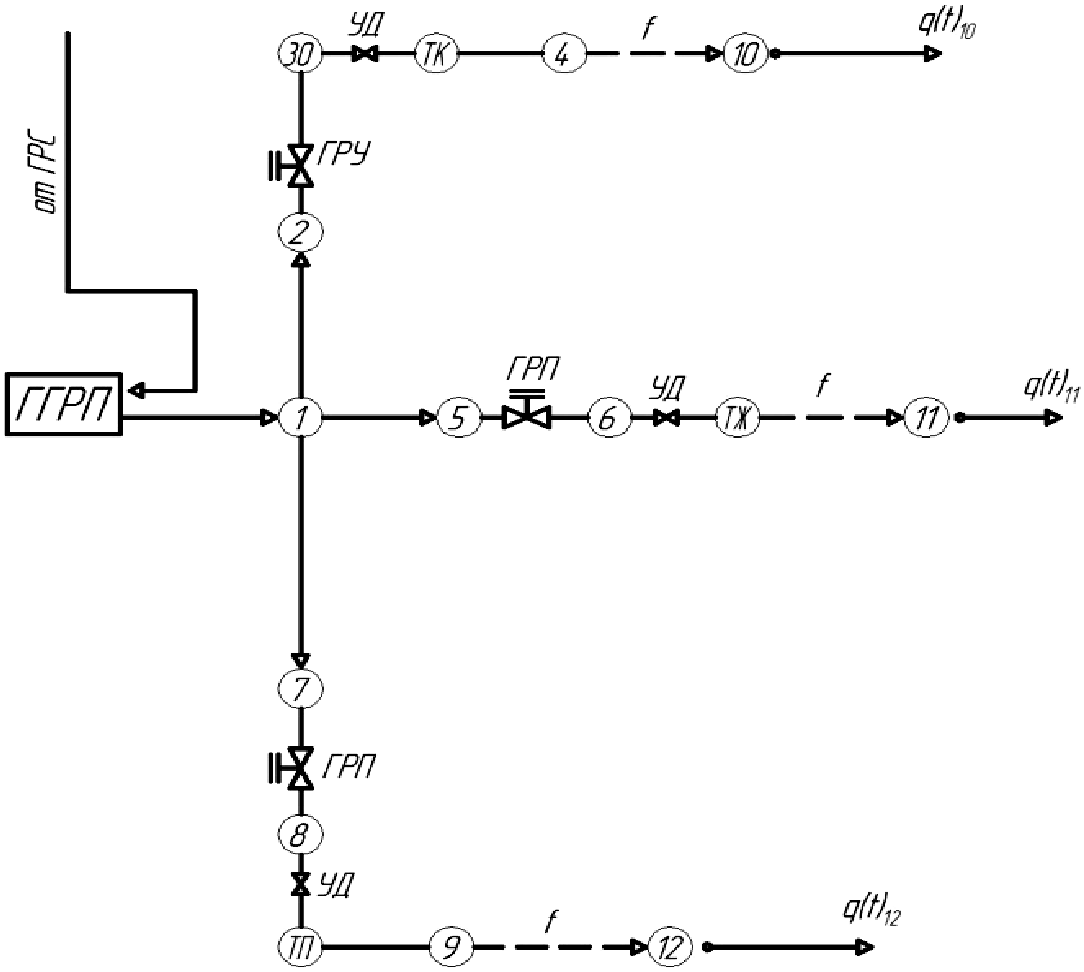

Fig. 1. Binary structural orgraph of a distribution network of medium (low) pressure:
1 — power supply node; 9 — industrial enterprise; ТЖ—11 — a residential area; 4 — boiler room;
3—ТК, 6—ТЖ, 8—ТП — technological pipelines with CT attached;
4—10, ТЖ —11, 9—12 — fictitious areas equivalent to the user's subsystems;
ТЖ – rigid pipe, ТК – square pipe, ТП – lifting pipe

The definition of an independent branch concludes that the latter is limited by fractures with fixed and specified pressures. The gas supply system in question has two gas regulating installations and a gas regulating station in place to supply a residential area (position (ТЖ—11) Fig. 1), as well as an urban gas regulating station as a common power supply source of the system that comprises three pressure stages: high, medium, and low. Two gas regulating installations fill up the boiler room and industrial enterprise, gas regulating station is a residential area that consumes low pressure gas.

The user's subsystems of a residential area, boiler room and industrial enterprise are equated with corresponding fictitious areas. Operating pressures after urban gas regulating station, gas regulating station, gas regulating installations (positions 1, 6, 3, 8 Fig. 1) are supported by constant ones and being known are included into a set of initial data.

Below is the block matrix representation of the system of equations as part of the mathematical management model of a network that has a medium (high) pressure stage produced for the most common (combined) configuration:

$$\begin{bmatrix} C_{n1\times p} \\ \hline C_{n1D\times p} \\ \hline C_{n2\times p} \end{bmatrix}^T \times \begin{bmatrix} \Delta P_{n1\times 1} \\ \hline \Delta P_{n1D\times 1} \\ \hline \Delta \widehat{P}_{n2\times 1} \end{bmatrix} = \left[M_{p\times g} \right] \left[\widehat{P}^*_{g\times 1} \right], \tag{1}$$

$$\begin{bmatrix} K_{n1\times r} \\ \hline O_{n1D\times r} \\ \hline O_{n2\times r} \end{bmatrix}^T \times \begin{bmatrix} \Delta P_{n1\times 1} \\ \hline \Delta P_{n1D\times 1} \\ \hline \Delta \widehat{P}_{n2\times 1} \end{bmatrix} = [0], \tag{2}$$

$$\begin{bmatrix} A_{n1\times m} \\ \hline A_{n1D\times m} \\ \hline A_{n2\times m} \end{bmatrix}^T \times \begin{bmatrix} Q_{n1\times 1} \\ \hline Q_{n1D\times 1} \\ \hline \widehat{q}(t)_{n2\times 1} \end{bmatrix} = [0], \tag{3}$$

where $\Delta P_i = P_{Hi}{}^2 - P_{ki}{}^2$ is a difference of the squares of absolute pressures at the start and end of the area i; $\widehat{P}_j^* = \widehat{P}_j^2$, $j \in Je \cup J\pi$ are fixed (defined) values of absolute pressure of gas in energy installation sources, final and interior nodes of the system; $\widehat{q}_i(t), i \in I^f$ are values of flow rate in fictitious areas specified in accordance with the condition (1).

For a medium (high) stage gas supply system that has a medium (high) stage let us introduce a system of equations as part of its management system operation.

1) $P_1^2 - P_3^2 = S_{1-2}Q_{1-2}{}^2 + S_{2-3}Q_{2-3}{}^2$;

2) $P_3^2 - P_{10}{}^2 = S_{3-TK}Q_{3-TK}{}^2 + S_{TK-4}Q_{TK-4}{}^2 + S_{4-10}\widehat{q}(t)_{10}{}^2$;

3) $P_1^2 - P_6{}^2 = S_{1-5}Q_{1-5}{}^2 + S_{5-6}Q_{5-6}{}^2$;

4) $P_6{}^2 - P_{11}{}^2 = S_{6-TЖ}Q_{6-TЖ}{}^2 + S_{TЖ-11}\widehat{q}(t)_{11}{}^2 \cdot \widehat{g}\left(t\right)_{11}{}^{1,75}$;

5) $P_1^2 - P_8^2 = S_{1-7}Q_{1-7}{}^2 + S_{7-8}Q_{7-8}{}^2$;

6) $P_8^2 - P_{12}{}^2 = S_{8-TП}Q_{8-TП}{}^2 + S_{TП-9}Q_{TП-9}{}^2 + S_{9-12}\widehat{q}(t)_{12}{}^2$;

7) $Q_{1-2} - Q_{2-3} = 0$;

8) $Q_{2-3} - Q_{3-\text{ТК}} = 0$;

9) $Q_{3-TK} - Q_{\text{ТК-4}} = 0$;

10) $Q_{1-5} - Q_{5-6} = 0$;

11) $Q_{5-6} - Q_{6-\text{ТЖ}} = 0$;

12) $Q_{6-TЖ} - \widehat{q}(t)_{11} = 0$;

13) $Q_{1-7} - Q_{7-8} = 0$;

14) $Q_{8-TП} - Q_{TП-9} = 0$;

15) $Q_{TП-9} - \widehat{q}(t)_{12} = 0$;

16) $Q_{\text{ТК}-4} - \widehat{q}(t)_{10} = 0$;

17) $Q_{7-8} - Q_{8-TП} = 0$.

The total number of equations (6 chain ones and 11-node balanced ones) agrees with a number of unknown flow rates Qi (11) and coefficients Si (6), i. e. the system of equations is closed and the problem of operation management is defined. Note the last summand of the equation (4) where a flow rate index unlike the rest of the summands is 1.75, since this summand allows for hydraulic losses in a fictitious area that equals a low pressure network of a residential area. Linearization (1)—(3) with deduction of linear summands results in a linear management model of the medium (high) pressure stage systems solved for a current iteration *k* which is shown in the block matrix form below:

$$\begin{bmatrix} C_{n1\times p} \\ \hline C_{n1D\times p} \\ \hline C_{n2\times p} \end{bmatrix}^T \times \left\{ \left[\begin{array}{c|c|c} 2\Delta P_{n1} & 0 & 0 \\ \hline 0 & 2\Delta P_{n1D} & 0 \\ \hline 0 & 0 & 2\Delta \hat{P}_{n2} \end{array} \right] \times \begin{bmatrix} \delta\bar{Q}_{n1\times 1} \\ \hline \delta\bar{Q}_{n1D\times 1} \\ \hline \delta\hat{\bar{q}}(t)_{n2\times 1} \end{bmatrix} + \left[\begin{array}{c|c|c} \Delta P_{n1} & 0 & 0 \\ \hline 0 & \Delta P_{n1D} & 0 \\ \hline 0 & 0 & \Delta P_{n2} \end{array} \right] \times \begin{bmatrix} 0 \\ \hline \delta S_{n1D\times 1} \\ \hline 0 \end{bmatrix} \right\} = 0, \quad (4)$$

$$\begin{bmatrix} K_{n1\times r} \\ \hline O_{n1D\times r} \\ \hline O_{n2\times r} \end{bmatrix}^T \times \left[\begin{array}{c|c|c} 2\Delta P_{n1} & 0 & 0 \\ \hline 0 & 2\Delta P_{n1D} & 0 \\ \hline 0 & 0 & 2\Delta \hat{P}_{n2} \end{array} \right] = [0], \quad (5)$$

$$\begin{bmatrix} A_{n1\times m} \\ \hline A_{n1D\times m} \\ \hline A_{n2\times m} \end{bmatrix}^T \times \left[\begin{array}{c|c|c} Q_{n1} & 0 & 0 \\ \hline 0 & Q_{n1D} & 0 \\ \hline 0 & 0 & \hat{q}(t)_{n2} \end{array} \right] \times \begin{bmatrix} \delta\bar{Q}_{n1\times 1} \\ \hline \delta\bar{Q}_{n1D\times 1} \\ \hline \delta\hat{\bar{q}}(t)_{n2\times 1} \end{bmatrix} = [0]. \quad (6)$$

A system number m (4)—(6) includes nodes with a non-specified pressure and fixed (interior) nodes with pressure that equals the operating pressure generated by a multitude of interior distribution stations (position 3, 6, 8 Fig. 1). The following linear system of equations is introduced for a gas supply system that has a medium (high) pressure stage (See Fig. 1):

I. Chain equations:

1) $2\Delta P_{1-2}{}^{(k-1)}\delta\bar{Q}_{1-2}{}^{(k)} + 2\Delta P_{2-3}{}^{(k-1)}\delta\bar{Q}_{2-3}{}^{(k)} + \Delta P_{2-3}{}^{(k-1)}\delta\bar{S}_{2-3}{}^{(k)} = 0$;

2) $2\Delta P_{3-TK}{}^{(k-1)}\delta\bar{Q}_{3-TK}{}^{(k)} + 2\Delta P_{TK-4}{}^{(k-1)}\delta\bar{Q}_{TK-4}{}^{(k)} + 2\Delta\hat{P}_{4-10}{}^{(k-1)}\delta\hat{\bar{q}}(t)_{10}{}^{(k)} + \Delta P_{3-TK}{}^{(k-1)}\delta\bar{S}_{3-TK}{}^{(k)} = 0$;

3) $2\Delta P_{1-5}{}^{(k-1)}\delta\bar{Q}_{1-5}{}^{(k)} + 2\Delta P_{5-6}{}^{(k-1)}\delta\bar{Q}_{5-6}{}^{(k)} + \Delta P_{5-6}{}^{(k-1)}\delta\bar{S}_{5-6}{}^{(k)} = 0$;

4) $2\Delta P_{6-TЖ}{}^{(k-1)}\delta\bar{Q}_{6-TЖ}{}^{(k)} + 1.75\Delta P_{TЖ-11}{}^{(k-1)}\delta\bar{q}(t)_{11}{}^{(k)} + \Delta P_{6-TЖ}{}^{(k-1)}\delta\bar{S}_{6-TЖ}{}^{(k)} = 0$;

5) $2\Delta P_{1-7}{}^{(k-1)}\delta\bar{Q}_{1-7}{}^{(k)} + 2\Delta P_{7-8}{}^{(k-1)}\delta\bar{Q}_{17-8}{}^{(k)} + \Delta P_{7-8}{}^{(k-1)}\delta\bar{S}_{7-8}{}^{(k)} = 0$;

6) $2\Delta P_{8-TП}{}^{(k-1)}\delta\bar{Q}_{8-TП}{}^{(k)} + 2\Delta P_{TП-9}{}^{(k-1)}\delta\bar{Q}_{1TП-9}{}^{(k)} + 2\Delta\hat{P}_{9-12}{}^{(k-1)}\delta\hat{\bar{q}}(t)_{12}{}^{(k)} + \Delta P_{8-TП}{}^{(K-1)}\delta\bar{S}_{8-TП}{}^{(k)} = 0$.

II. Node balance equations:

7) $Q_{1-2}{}^{(k-1)}\delta\bar{Q}_{1-2}{}^{(k)} + Q_{2-3}{}^{(k-1)}\delta\bar{Q}_{2-3}{}^{(k)} = 0$;

8) $Q_{2-3}{}^{(k-1)}\delta\bar{Q}_{2-3}{}^{(k)} + Q_{3-TK}{}^{(k-1)}\delta\bar{Q}_{3-TK}{}^{(k)} = 0$;

9) $Q_{3-TK}{}^{(k-1)}\delta\bar{Q}_{3-TK}{}^{(k)} - Q_{TK-4}{}^{(k-1)}\delta\bar{Q}_{TK-4}{}^{(k)} = 0$;

10) $Q_{1-5}{}^{(k-1)}\delta\bar{Q}_{1-5}{}^{(k)} - Q_{5-6}{}^{(k-1)}\delta\bar{Q}_{5-6}{}^{(k)} = 0$;

11) $Q_{5-6}{}^{(k-1)}\delta\overline{Q}_{5-6}{}^{(k)} - Q_{6-ТЖ}{}^{(k-1)}\delta\overline{Q}_{6-ТЖ}{}^{(k)} = 0$;

12) $Q_{6-ТЖ}{}^{(k-1)}\delta\overline{Q}_{6-ТЖ}{}^{(k)} + \widehat{q}(t)_{11}{}^{(k-1)}\delta\overline{\widehat{q}}(t)_{11}{}^{(k)} = 0$;

13) $Q_{1-7}{}^{(k-1)}\delta\overline{Q}_{1-7}{}^{(k)} - Q_{7-8}{}^{(k-1)}\delta\overline{Q}_{7-8}{}^{(k)} = 0$;

14) $Q_{8-ТП}{}^{(k-1)}\delta\overline{Q}_{8-ТП}{}^{(k)} - Q_{ТП-9}{}^{(k-1)}\delta\overline{Q}_{ТП-9}{}^{(k)} = 0$;

15) $Q_{ТП-9}{}^{(k-1)}\delta\overline{Q}_{ТП-9}{}^{(k)} - \widehat{q}(t)_{12}{}^{(k-1)}\delta\overline{\widehat{q}}(t)_{12}{}^{(k)} = 0$;

16) $Q_{ТК-4}{}^{(k-1)}\delta\overline{Q}_{ТК-4}{}^{(k)} - \widehat{q}(t)_{10}{}^{(k-1)}\delta\overline{\widehat{q}}(t)_{10}{}^{(k)} = 0$;

17) $Q_{7-8}{}^{(k-1)}\delta\overline{Q}_{7-8}{}^{(k)} - Q_{8-ТП}{}^{(k-1)}\delta\overline{Q}_{8-ТП}{}^{(k)} = 0$.

The peculiarity of a linear system of equations itself and the one above is a resulting opportunity to define hydraulic setting not only of a set of CT pipes but also of a set of regulating stations (position 3—ТК, 6—ТЖ, 8—ТП on Fig. 1), and a corresponding set of distribution stations installed in succession with CT pipes. The rest of distribution stations operating as part of lower hierarchy pressure stages are considered in a hydraulic set of fictitious areas.

Hydraulic setting of fictitious areas is determined at the stage of preliminary flow distribution as part of designing for the unperturbed state of the system [1]. Note that node balance equations for fixed nodes setting restrictions on the system are not included in the mathematical model (position 1, 10, 11, 12 on Fig. 1) or otherwise we have no right to include chain (i. e. 6 chains of Fig. 1) of the equation that are restricted by these nodes.

The main principles behind algorithmic design for the implementation of a management model of the operation of a gas supply system that has a medium (high) pressure stage are pretty much the same as for low pressure systems: a) to search for the zero iteration; b) to choose the way iteration (initial) perturbation introduced into the system tends to distribute. The zero iteration is determined for the unperturbed state of the system at the closing stage of the project task (precise flow distribution) [2].

The operation management model for (1)—(3), (4)—(6) is dominated by flow rates predicted for a gas consumption $\widehat{q}_j(t)$, $\delta\overline{\widehat{q}}_j(t)$ instead of those of fictitious areas $\widehat{Q}_i^f(t)$, $\delta\overline{\widehat{Q}}_i^f(t)$. This substitution is due to the assumption (1) for low as well as medium (high) pressure systems. It does not really change the modeling results (for the majority of real situations) as it is different in its form not the content.

Therefore we have a new algorithmic form:

$$\delta\hat{\bar{q}}(t)_j^{(k)} = \frac{2\left[\hat{q}(t)_j^{(k-1)} - \hat{q}(t)_j^{(k-2)}\right]}{\left[\hat{q}(t)_j^{(k-1)} + \hat{q}(t)_j^{(k-2)}\right]},\ j \in I^f. \tag{7}$$

The values of the initial variable on the current iteration to κ are:

$$Q_i^{(k)} = Q_i^{(k)} + Q_i^{(k-1)}\delta\bar{Q}_i^{(k)},\ i \in I \not\subset I^f;$$

$$S_i^{(k)} = S_i^{(k)} + S_i^{(k-1)}\delta\bar{S}_i^{(k)},\ i \in I_D;$$

$$\hat{Q}_i^{(k)} = \hat{Q}_i^{(k)} + \hat{Q}_i^{(k-1)}\delta\hat{\bar{q}}(t)_i^{(k)},\ i \in I^f, j \in I^f;\quad S_i^{(k)} \geq S_{i0},\ i \in I_D.$$

Essentially Formula (7) shows iteration re-distribution of the variable $\delta\hat{\bar{q}}(t)_j^{(k)}$ and $\hat{Q}_i^{(k)}$ in case of non-formalized distribution of predicted gas consumption. In a particular case of linear dependence of flow rate of gas consumption on a time parameter t, Formula (7) transforms into the algorithmic form below:

$$\delta\hat{\bar{q}}(t)_j^{(k)} = \frac{2\left[\hat{q}(t)_j^{np} - \hat{q}_j^{(0)}\right]}{\left[\hat{q}_j^{(0)} + \hat{q}(t)_j^{np}\right]\cdot K} = const,\ j \in I^f, \tag{8}$$

where $\hat{q}(t)_j^{np}$ is a gas flow rate consumed at the time t from the node j of the system; $\hat{q}_j^{(0)}$ is the same for the zero iteration, i. e. before the modeling of the operation process started; K is a number of iterations within the modeling time.

There is a principal opportunity to split the entire time period of modeling of the operation process into a variety of line segments $\Delta q(t)_{ij}$ (where $\Delta q(t)_{ij}$ is linear changes in flow rates for a time interval Δt_i from the node j of the system), i. e. piecewise linear approximation $\hat{q}_j = q_j(t)$. In this case Form (8) is used to define values $\delta\hat{q}(t)_j^{(\kappa)} = const$ on the time interval Δt_i. According to the modeling results, the pressure values are defined in all of the nodes of the system.

A high pressure distribution system of the branched structure with one power supply node and a group of various users (Fig. 2) which is supplied from the main gas regulating station with gas regulating station installed after gas regulating installation, gas regulating station on short technological pipes. Gas regulating station and cupboard regulator (position 12 Fig. 1) supplies a residential area (Fig. 2) equated by two fictitious branching (position T—27 and T—29 Fig. 2).

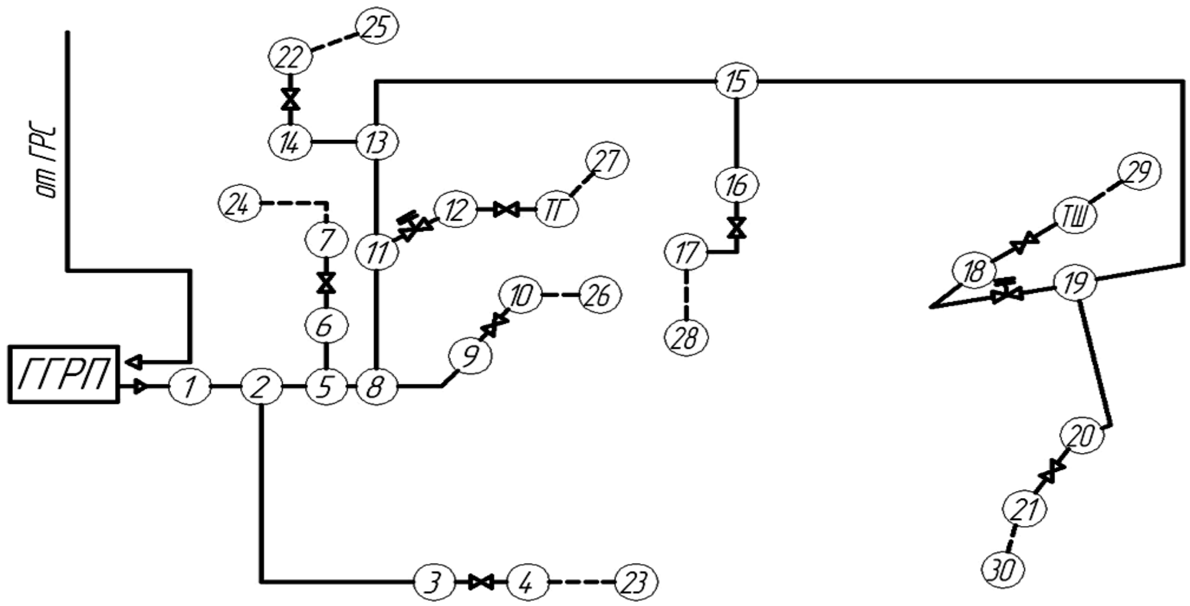

Fig. 2. Binary structural orgraph of a high pressure distribution system:
1 — power supply node; 4 — bread factory; 7 — boiler room; 10 — industrial enterprise № 3;
12 — ГРП (gas distribution station; (12—ТГ) — technological pipeline; 22 — industrial enterprise № 1;
17 — industrial enterprise N 2; 18 — ШРП (cupboard regulator); (18—ТШ (screw transporter) — technological pipeline; 21 — bath and laundry room; 3.6,9.14.16.20 — gas regulating installation;
23—30 — final nodes of the system; 2, 5, 8, 11, 13, 15, 19 — branching nodes; — controlled throttle;
1, 4, 7, 10, ТГ (corrugated pipes), 17, ТШ (screw transporter), 21, 22 — energy nodes of a distribution network;
— discharge regulator as part of gas regulating station (ШРП cupboard regulator)

The latter is made possible thanks to the identical movement patterns in nodes N 27, N 29, which allows one to combine them to make up a single gas supply system of a residential area. In the final nodes of a two-stage gas supply system the pressure is accepted to equal the barometric which is consistent with the perturbation theory.

The model (4)—(6) provides "a snapshot" of the system's state at the time moment t (Table 1, 2). These tables also indicate the accuracy of gas consumption prediction.

Table 1

Prediction and accuracy of gas consumption prediction of a high pressure gas supply system (Fig. 1, variant 1)

Area designation	Before the management started, m^3/h	Gas consumption prediction, m^3/h	Accuracy of the prediction, m^3/h
4—23	134.5	108.097	109.754
7—24	11744.7	9429.8	9431.3
22—25	2270.2	2807.7	2809.4
ТГ—27	2079.4	1871.2	1872.8
17—28	2648.7	3177.3	3179.0
ТШ—29	2582.5	2324.2	2325.9
10—26	2354.4	2822.5	2824.2
21—30	347.7	347.7	349.3

Table 2

Prediction and accuracy of gas consumption prediction of a high pressure gas supply system (Fig. 2, variant 2)

Area designation	Before the management started, m^3/h	Gas consumption prediction, m^3/h	Accuracy of the prediction, m^3/h
4—23	134.5	161.4	152.67
7—24	11744.7	14121.6	14113.4
22—25	2270.2	1817.7	1809.2
ТГ—27	2079.4	2286.8	2278.4
17—28	2648.7	2122.0	2113.5
ТШ—29	2582.5	2839.8	2831.3
10—26	2354.4	1885.8	1887.3
21—30	347.7	347.7	339.6

For certain characteristics there is a local dispersion which, however, does not cause distortions in its configuration. As mentioned above, characteristics of a throttle change their configuration in case there is a system's reconstruction, repair works, emergencies involving certain areas or their groups being shut off. Changes in gas flow rates as part of a consumption system are not influential on the characteristics of a throttle and merely cause a design point to move along its trajectory. The characteristics of a throttle help avoid an iteration solution of large dimensional non-linear algebraic systems of equations when operation signals are developed to readjust executive operation management systems. Synthesized in good time, the characteristics of a throttle can be improved in the course of procedures involving changes in configuration and structure of gas supply.

Conclusions

A mathematical model of operation management of a medium (high) pressure was obtained which realizes the management principle according to perturbation introduced into the hydraulic setting of a set CT pipes as executive bodies of the system operation. The above model allows for a possible coverage of a medium (high) pressure stage of several hierarchies followed by a successive location of distribution stations and CT pipes which causes interior chains to appear. The operation management model accounts for the location of distribution stations in relation to CT pipe (before and after CT pipe) and enables an accurate hydraulic setting within the time t of distribution stations and CT pipe as well.

An algorithm for synthesizing the characteristics of a throttle was developed that allows one to obtain speedy results of gas consumption prediction.

Based on the calculation experiments, a substantially high accuracy level of gas consumption prediction was shown.

References

1. G. Forsythe, M. Malcolm, K. Moler, *Machine Methods of Mathematical Calculations* (Moscow, 1980) [in Russian].
2. D. B. Bayasanov, A. A. Ionin, *Distribution Systems of Gas Supply* (Moscow, 1977) [in Russian].
3. G. N. Martynenko, *Modeling of Processes of Operative Management of the Gas Supply City Systems on the Basis of Factor Analysis: abstract of Ph. D. thesis* (Voronezh, 2004) [in Russian].
4. M. Ya. Panov, *Variationally Topological Methods of Modeling and Structure-Parameter Optimization of Hydraulic Systems: abstract of D. Sc. thesis* (Voronezh, 1994) [in Russian].