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Analysis of the impact of local pipeline segment failure on the hydraulic reliability of gas pipeline network

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Abstract

Taking reliability as the starting point, this paper analyzes the hydraulic conditions of urban gas transmission and distribution networks and the reliability of gas supply. Based on Pipeline Studio software and combined with practical cases, it explores the impact of partial pipeline failure on the reliability of system gas supply. The research results indicate that a complete and continuous pipeline network has the greatest impact on the reliability of system gas supply when the pipeline sections on both sides of the gas supply point fail. Properly enlarging the diameter of the pipeline section can effectively improve the reliability of gas supply under accident conditions.

Keywords

Urban gas pipe network; hydraulic reliability; hydraulic calculation; accident conditions.

1. Introduction

Gas safety involves thousands of households, relates to the safety of people's lives and property, and is related to the harmonious and stable social situation. The safety and reliability of gas pipelines play a significant role in ensuring the safe supply of gas.

If the topology of the natural gas pipeline network is unreasonable or there is no reasonable adjustment of the operation plan of the pipeline network after the local failure occurs, the negative effect of the local failure may spread to a large area of the pipeline network, and lead to a significant decline in the gas supply capacity of the entire pipeline network or to some key users. Therefore, it is necessary to study the reliability of gas pipe network. The classical reliability theory only considers two states of reliability and unreliability, and its reliability evaluation index has little information, which can not fully evaluate the gas supply support ability of gas pipe network system. The existing reliability evaluation methods focus on the reliability evaluation of pipeline facilities, but do not fully consider the gas supply capacity and requirements of the pipeline network[1-3]. Therefore, it is necessary to develop reliability evaluation methods that consider both structural reliability and hydraulic reliability of the gas pipeline network[4].

2. Hydraulic reliability of the pipe network

2.1. Node reliability

The failure of local pipe sections in the pipeline network causes local gas supply interruption, and the degree of influence on the hydraulic parameters of each node in the pipeline network is different. The degree of influence of each node can be expressed by the node gas supply guarantee coefficient, which is the ratio of the actual flow rate of the node under accident conditions to the flow rate of the node under normal conditions. The expression is as follows:

$$x_i = \frac{Q_i'}{Q_i} \tag{1}$$

Where, Q_i' is the flow rate of node i under accident condition, m^3/h; Q_i is the flow rate of node i under normal working conditions, m^3/h; x_i is the gas supply guarantee coefficient of node i. If $x \geq 70\%$, the gas supply of node i is considered reliable[5].

The gas supply guarantee coefficient can well reflect the reliability of the gas pipe network when it fails locally, but some hydraulic calculation simulation software does not support to display the node flow under the accident condition. In this case, the node pressure ratio between the accident condition and the normal condition can be used as the reliability evaluation index. Node reliability is defined as:

$$R_i = \frac{P_i'}{P_i} \tag{2}$$

Where, P_i' is the pressure of node i under accident condition, MPa, P_i is the pressure of node i under normal condition, MPa, (in this paper, the design pressure of pipe network is the pressure under normal condition); R_i is the node reliability of node i.

2.2. System reliability

Under accident conditions, the flow rate and pressure drop of each pipe section may change, the total pressure drop of the system is greatly different from the design value, and the flow resistance coefficient of the pipe network increases significantly, which usually leads to the reduction of user flow. In order to achieve an acceptable flow rate under accident conditions, a certain pressure reserve is required during design to maintain the user's flow rate under accident conditions, so the design pressure drop is different from the accident pressure drop. The pressure reserve of pipe network can be characterized by the calculated pressure drop utilization degree, which is as follows[6]:

$$y = \frac{\left(P_A^{\ 2} - P_B^{\ 2}\right)_l}{\left(P_A^{\ 2} - P_B^{\ 2}\right)_s} \tag{3}$$

Where, l indicates normal working conditions; s indicates the accident condition; P_A is the pressure of node A, MPa; P_B indicates the pressure of node B (MPa).

3. Case Analysis

According to the controlled detailed planning of a new district in a city, by 2028, the planned population of the new district is nearly 700,000 people, the gas consumption quota is 2700MJ/person • year, the low calorific value of natural gas is $35.81MJ/m^3$, the annual gas consumption is $18797.8 \times 104m^3/a$, and the hourly calculated flow rate is $5.27 \times 10^4 m^3/h$. In this paper, the hourly flow rate is used as the total gas consumption. The design pressure is 400KPa (gauge pressure), the minimum allowable pressure of the pipe network is 250KPa (gauge pressure), the gate station is located in the northeast corner of the area, the number of pipe network segments is 82, and the number of nodes is 53. The regional pipe network planning diagram is shown in Figure 1.

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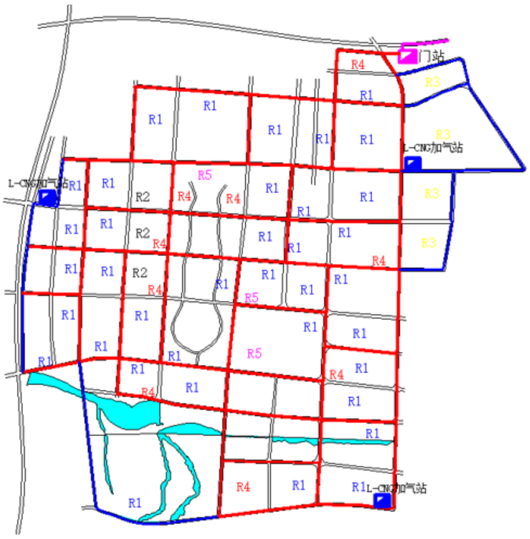

Fig. 1 Planning diagram of gas pipe network in a new district of a city

3.1. Hydraulic calculation parameters under working conditions

After hydraulic calculation, the minimum pressure is 276.2KPa, which meets the design requirement of the minimum pressure not less than 250KPa. The maximum pipe section flow rate is 15.9m/s, and the pipe network pressure decreases steadily and evenly from the air source point to the lowest point. The hydraulic calculation results are reasonable and effective. The hydraulic calculation parameters of the pipe network are shown in Table 1.

Table 1 Hydraulic calculation results of each working condition

	Maximum section flow（m^3/h）	Minimum nodal pressure(gauge KPa）	Maximum velocity（m/s）	Maximum pipe diameter(mm)
Normal working condition	30820.3	276.2	15.9	355
The first accident condition	52804.4	19.0	59.1	355
The second accident condition	43336.5	-101.3	304.8	355
The first accident condition after correction	52804.1	273.4	19.8	400
The second accident condition after correction	53321.7	273.2	21.6	400

3.2. Hydraulic calculation parameters in accident conditions

Considering the impact of pipeline failure caused by welding anticorrosion defects or third party damage on pipe network, accident condition analysis should be conducted during the design. The pipe network layout is square, continuous and complete, and there is no pipe section with particularly important structure. Therefore, the effect of failure of pipe section with large flow on pipe network should be mainly considered. Combined with the pipe network layout and the hydraulic calculation results of normal working conditions, it is determined that the two pipe sections 0-2 and 0-3 connected to the pipe network are the important pipe sections, and the two pipe sections are respectively broken as the two most unfavorable accident conditions for analysis. The schematic diagram of the two accident conditions is shown in Figure 2, and the main parameters of the hydraulic calculation results are shown in Table 1.

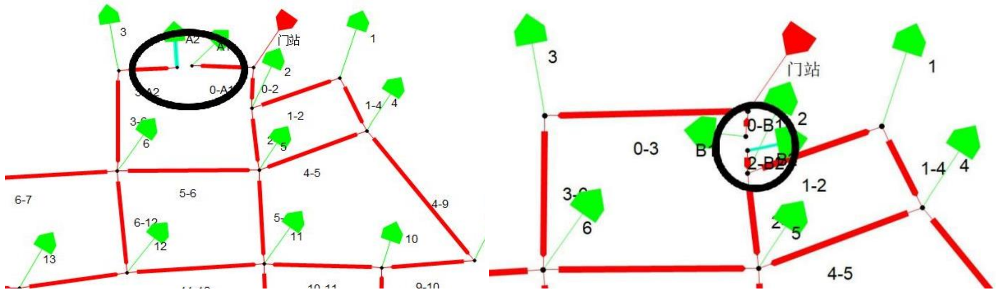

Fig. 2 Schematic diagram of accident condition 1(left) and accident condition 2(fight)

3.3. Reliability analysis

3.3.1. Node reliability

Node reliability refers to the ratio of node pressure in accident condition to node pressure in normal condition. According to equation (2), node reliability in accident condition 1 and accident condition 2 can be calculated. The proportion of nodes whose node reliability is greater than or equal to 1 and 0.7 under the two conditions is shown in Table 2. It can be seen from the data in the table that at the time of the accident, only two nodes have a reliability greater than or equal to 0.7, and 66% of nodes have a reliability lower than 0.3. When accident 2 occurs, the reliability of only one node is greater than or equal to 0.7, and the reliability of other nodes is very low, and even some nodes have negative reliability, indicating that there is no flow of these nodes in the pipe network.

Table 2 The proportion of nodes whose reliability is greater than or equal to 1 and 0.7 in accident 1 and accident 2 nodes

	R_i≥1	R_i≥0.7	R_i≥1
The first accident condition	0	3.77%	0
The second accident condition	0	1.89%	0
The first accident condition after correction	96.23%	100%	96.23%
The second accident condition after correction	98.11%	100%	98.11%

3.3.2. System reliability

The reliability of the system is expressed by the utilization degree of calculated pressure drop. According to equation (3), the normal working condition and accident reliability can be calculated, as shown in Table 3.

Table 3 System reliability under various operating conditions

	Maximum node pressure（KPa）	Minimum node pressure（KPa）	Reliability

Normal working condition	400	276.2	/
The first accident condition	400	19.0	0.524
The second accident condition	400	-101.3	/
The first accident condition after correction	400	273.4	0.982
The second accident condition after correction	400	273.2	0.974

3.4. Analysis and improvement measures

The data in Table 3.1 show that under the first accident condition, the node pressure is significantly reduced. There are only two nodes with node pressure exceeding 250 kPa, the pressure of most nodes is only tens of thousands, and the flow rate of almost all pipe sections is greatly increased to the maximum of 59.1 m / s.The second accident is more serious, the pressure of some nodes is negative, and the maximum flow rate of the pipe section reaches 304.8m/s. Such calculation results are completely inconsistent with the design requirements of the pipe network, and any accident condition will seriously affect the gas supply of the pipe network. According to the data in Table 3.2, there are only 2 nodes with the reliability of accident node 1 reaching 0.7, and only 1 node with the reliability of accident node 2 reaching 0.7, indicating that the accident conditions have a great impact on the hydraulic conditions of the pipe network.

According to the analysis of the accident conditions, the pipe network has an ideal structure, and the reasons for serious hydraulic imbalance in these two accident conditions are the same, because the pipe section bears a large flow rate, and the flow rate should be borne by other pipes in case of failure. If other pipe diameters only meet the requirements of normal working conditions, when this pipe section fails, other pipe sections cannot bear the flow rate of this pipe section at the same time, affecting the gas supply of the pipe network. The solution is to expand the diameter of 0-2, 0-3 and other pipe sections with large pressure drop according to the hydraulic calculation results of accident conditions.

After correction, the hydraulic calculation results show that after correction, the pipe section flow, pressure drop, velocity, node flow, pressure, reliability and other parameters of the pipe network are normal, and the hydraulic condition of the pipe network is ideal, which can cope with the serious consequences caused by the failure of important pipe sections.

4. Conclusion and prospect

(1) the integrity of pipeline network structure is the basic requirement of gas pipeline network, if the pipe diameter is not reasonable, the failure of some pipe sections may seriously affect the gas supply.

(2) After enlarging part of the pipe diameter, the reliability of the notes and the system in the accident condition is greatly improved. Enlarging part of the pipe diameter can effectively improve the hydraulic reliability in the accident condition.

(3) The hydraulic calculation of gas pipe network should carry out the accident condition analysis to avoid the serious consequences caused by the failure of important pipe sections.

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