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Simulation and Test for Hydraulic Reliability of Gas Pipeline Network with Two-ring Parallel

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ABSTRACT

Based on the momentum equation, continuity equation and state equation, the unstable flow model of the gas pipeline network with two-ring parallel having distributing points was established and we got the analytic solution. To the actual gas pipeline network model, we analyzed the characteristic values—nodes, volume and network flow reliability's changing trend on the working condition, node leakage condition and pipe cut-off condition. What we did can provide support for the monitoring of faulted gas pipeline network and shorten the duration of the faulted gas pipeline network condition, and then the hydraulic reliability of gas pipeline network can be increased.

INTRODUCTION

The main function of the municipal gas pipeline network is to supply users with the gas meeting the users' requirements of certain pressure and flow volume. Under normal working conditions, the pressure and flow volume of gas meet the requirements for each node (user) in the municipal gas pipeline network. When an accident happens in a node in the gas pipeline network and results in gas leakage, then it will have some impacts on the nearby node's parameters of pressure and flow volume [1].

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CALCULATE METHODS OF HYDRAULIC RELIABILITY

Based on the relationship between flow volume and pressure of nodes, the gas pipeline network is divided into normal supply, part supply and interrupted supply. The hydraulic reliability can be described in the following three characteristic values: nodes flow reliability, volume flow reliability and the network flow reliability [2].

To a single node in all m states, the ratio of the actual total gas flow and the total nodal demand gas flow. And its expression is formula (1).

$$R_{ni} = \sum_{s=1}^{m} V_{is} / \sum_{s=1}^{m} V_i^s = \sum_{s=1}^{m} Q_{is} \cdot t_s / (\sum_{s=1}^{m} Q_i^s \cdot t_s) \tag{1}$$

During the duration, for all n nodes, at all m states, the ratio of the actual total volume of gas consumption and the required total volume of gas consumption. And its expression is formula (2).

$$R_{nv} = \sum_{s=1}^{m}\sum_{i=1}^{n} V_{is} / (\sum_{s=1}^{m}\sum_{i=1}^{n} V_i^s) = \sum_{s=1}^{m}\sum_{i=1}^{n} Q_{is} \cdot t_s / (\sum_{s=1}^{m}\sum_{i=1}^{n} Q_i^s \cdot t_s) \tag{2}$$

In addition to the nodal factors, network flow reliability also includes the time factors. The third characteristic value can be expressed as formula (3).

$$R_{nw} = R_{nv} \sum_{i=1}^{n} (Q_i^s / \sum_{i=1}^{n} Q_i^s) R_{ni} (\sum_{s=1}^{m}\sum_{i=1}^{n} \alpha_{is} t_{is} / mT) \tag{3}$$

The nodal factor of the gas pipeline network's network flow reliability only considers the degree of satisfaction with the nodes' (users') actual gas consumption to the totally supplied gas volume under. Volume and network flow reliability of gas pipeline network can be used to analyze whether the supplied gas meets the requirement of the design and evaluate whether the operating state is reasonable [3].

SIMULATION AND TEST

Solution of Mathematical Model

The unstable flow model of gas pipeline introduce space unit pulse function $\delta(x)$ and time unit pulse function $\sigma(\tau)$ to describe the time and location of gas distributing points' nodal flow [4]. The unstable flow model is formula (4).

$$\frac{\partial p}{\partial \tau} = a^2 \frac{\partial^2 p}{\partial x^2} + a^2 \sum_{j=0}^{m} (p_{in,j} - p_{out,j}) \delta'(x - x_j) \sigma(\tau - \tau_j) - c^2 \sum_{i=1}^{n} \frac{1}{A_i} M_{mi} \delta(x - x_i) \sigma(\tau - \tau_i) \tag{4}$$

Schematic diagram of gas pipeline network with two-ring parallel is shown in figure 1. We should take the intersection O of the connected pipe and main pipe as the origin. Assuming the length of connected pipe is l, the left main pipe's length is l1 and the right one is l2. The flow model is formula (5).

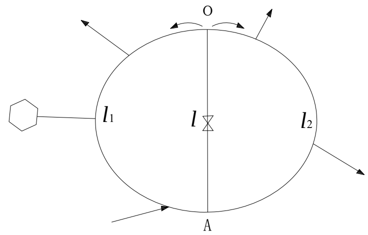

Figure 1. Schematic diagram of gas pipeline network with two-ring parallel.

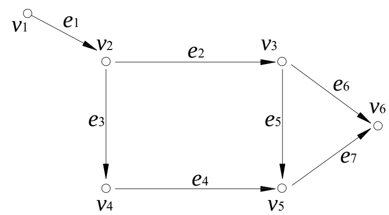

Figure 2. Schematic diagram of pipeline network.

$$\begin{cases} \frac{\partial^2 p_1}{\partial x_1^2} - \frac{1}{a_1^2}\frac{\partial p_1}{\partial \tau} = \sum_{i=1}^{n_1} \frac{k_1}{A_i} M_{m1i}\delta(x_1 - x_{1i})\sigma(\tau - \tau_{1i}) \;\; \tau > 0, 0 < x_1 < l_1 + l, x_{1i} \in (0, l_1) \\ \frac{\partial^2 p_2}{\partial x_2^2} - \frac{1}{a_2^2}\frac{\partial p_2}{\partial \tau} = \sum_{i=1}^{n_2} \frac{k_2}{A_i} M_{m2i}\delta(x_2 - x_{2i})\sigma(\tau - \tau_{2i}) \;\; \tau > 0, 0 < x_2 < l_2, x_{2i} \in (0, l_2) \end{cases} \tag{5}$$

Utilizing the Laplace transformation to solve the mathematical model, we can get the solution as formula (6) and (7).

$$\begin{aligned} p_1(x_1,\tau) = p_0 - \frac{c^2}{2}\sum_{i=1}^{n_1}\frac{1}{A_i}\sigma(\tau-\tau_{1i})\int_0^{\tau-\tau_{1i}} M_{m1i}[f_{11}(x_1,\tau-\tau_{1i}-t) - f_{13}(x_1,\tau-\tau_{1i}-t)] \\ \cdot dt - \frac{c^2}{2}\sum_{i=1}^{n_2}\frac{1}{A_i}\sigma(\tau-\tau_{2i})\int_0^{\tau-\tau_{2i}} M_{m2i}\cdot f_{12}(x_1,\tau-\tau_{2i}-t)dt \end{aligned} \tag{6}$$

$$\begin{aligned} p_2(x_2,\tau) = p_0 + \frac{c^2}{2}\sum_{i=1}^{n_1}\frac{1}{A_i}\sigma(\tau-\tau_{1i})\int_0^{\tau-\tau_{1i}} M_{m1i}[f_{21}(x_2,\tau-\tau_{1i}-t) - f_{22}(x_2,\tau-\tau_{1i}-t) \\ + f_{24}(x_2,\tau-\tau_{1i}-t) + f_{26}(x_2,\tau-\tau_{1i}-t)]dt + \frac{c^2}{2}\sum_{i=1}^{n_2}\frac{1}{A_i}\sigma(\tau-\tau_{2i})\int_0^{\tau-\tau_{2i}} M_{m2i} \\ \cdot[-f_{23}(x_2,\tau-\tau_{2i}-t) + f_{25}(x_2,\tau-\tau_{2i}-t) - f_{27}(x_2,\tau-\tau_{2i}-t)]dt \end{aligned} \tag{7}$$

Spot Test

Take a district annular gas pipeline network in Chengdu as a test object and the simplified gas pipeline network is shown in the figure2.v1 is the gas source point and v2~v6 is the nodes, each demand pressure is 2600Pa, minimum required pressure is 2000Pa, gas source point v1 supplies gas of 3000Pa and we take 24h as the duration.

The initial pressure of gas pipeline network is 3000Pa. The length and diameter of gas pipeline are shown in table I.

TABLE I. LENGTH AND DIAMETER OF GAS PIPELINE.

Pipeline	e_1	e_2	e_3	e_4	e_5	e_6	e_7
L (m)	200	1000	1100	800	800	1000	350
D(mm)	400	350	300	300	150	300	200

TABLE II. FLOW AND PRESSURE DEMAND OF PIPELINE NETWORK NODES.

node	22~02h		02~06h		06~10h		10~14h		14~18h		18~22h	
	Q_i m^3/h	p_m Pa	Q_i m^3/h	p_m Pa	Q_i m^3/h	p_m Pa	Q_i m^3/h	p_m Pa	Q_i m^3/h	p_m Pa	Q_i m^3/h	p_m Pa
v_2	25	2962	30	2924	50	2902	60	2881	40	2926	35	2953
v_3	15	2910	20	2865	25	2821	30	2723	30	2815	20	2899
v_4	10	2893	20	2857	30	2782	40	2646	30	2780	25	2871
v_5	10	2892	15	2854	20	2778	25	2643	20	2772	15	2873
v_6	5	2893	10	2856	15	2785	20	2654	15	2781	10	2876
Total	65	—	95	—	140	—	175	—	135	—	105	—

RESULT AND DISCUSSIONS

Each node's gas flow demand of gas pipeline network is shown in table II. Make the data-fitting with Polynomial, the calculated pressure is shown in table II.

To simulate the 25m3/h gas leakage in e3-pipe, we can add the amount of leakage as the demand of v4-node:

$$M'_{v4}(t) = 0.0020t^4 - 0.0864t^3 + 0.9787t^2 - 0.5489t + 35.2579$$

Take v4-node's new flow into the analytic solution of unstable flow and the entire network's pressure and flow can be calculated. The result is shown in table III.

When an accident happens, it's necessary to isolate the pipe for maintenance. e3-pipe cut-off, the flow of v4-node remain the demand flow on normal working condition. The calculated pressure and flow of nodes are shown in table IV.

The nodes flow reliability is shown in figure3 and each node's volume and network flow reliability with v4-node failure are shown in figure4. The curves of each node's nodes flow reliability with e3-pipeline cut-off are shown in figure5. The volume reliability is 0.775 and the network reliability is 0.414.

CONCLUSIONS

The unstable flow model of network was established based on the continuity and momentum formula and the analytic solution could be got. We simulated, tested and analyzed the changing trend of the characteristic values for the network's hydraulic reliability with pipeline leakage and pipeline cut-off. According to the results, when supervising the actual flow volume of nodes(users) starting to decrease, we can inspect the network urgently and find out the leaking node or pipeline to shorten the duration of the faulted condition and confine the scope and extent of the impacts on the network's hydraulic reliability due to the leakage of pipeline.

TABLE III. FLOW AND PRESSURE OF NODES WITH v_4-NODE LEAKAGE.

node	22~02h		02~06h		06~10h		10~14h		14~18h		18~22h	
	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa
v_2	25	2962	30	2748	48.0	2553	50.2	2420	32.6	2399	27.2	2362
v_3	15	2910	20	2693	22.4	2482	20.7	2287	21.5	2308	14.6	2319
v_4	10	2893	20	2599	20.5	2281	0	1984	6.6	2029	6.3	2038
v_5	10	2892	15	2654	16.1	2389	10.9	2114	10.4	2162	8.3	2183
v_6	5	2893	10	2684	12.6	2422	10.8	2176	9.2	2224	6.3	2243
Total	65	—	95	—	120	—	92.6	—	80.3	—	62.7	—

TABLE IV. FLOW AND PRESSURE OF NODES WITH e_3-PIPELINE CUT-OFF.

node	22~02h		02~06h		06~10h		10~14h		14~18h		18~22h	
	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa	Q_i m³/h	p_m Pa
v_2	25	2962	30	2924	50	2902	60	2881	40	2926	35	2953
v_3	15	2803	20	2722	25	2613	23.7	2375	29.6	2586	20	2768
v_4	9.5	2545	17.2	2442	10.9	2080	0	1468	8.8	2052	21.2	2433
v_5	9.7	2572	12.9	2449	9.6	2140	0	1573	8.5	2110	13.3	2475
v_6	5	2703	10	2692	12.5	2408	3.9	2023	11.8	2376	10	2651
Total	64.2	—	90.1	—	108	—	87.6	—	98.7	—	99.5	—

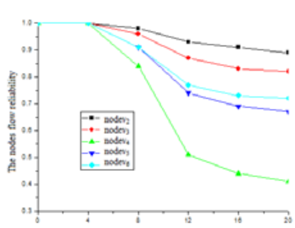

Figure 3. Nodes flow reliability (v_4-node leakage).

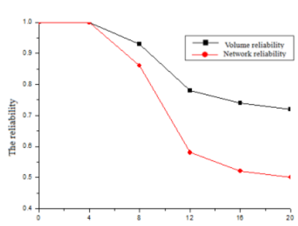

Figure 4. Volume and network flow reliability (v_4-node leakage).

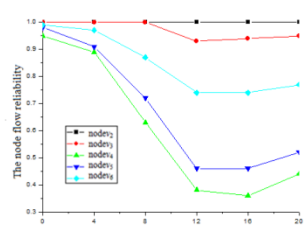

Figure 5. Nodes flow reliability (e_3-pipeline cut-off).

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