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Locating Gas Pipeline Leakage Based on Stimulus-Response Method

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Abstract

Gas pipeline leakage leads to significant environmental damages, industrial hazards and personal injuries, so detecting and locating the leakage location without delay is essential to lighten or avoid its harms. The stimulus-response method, a newly proposed technique of pipeline leakage detection and location has received much attention for its benefit of strong detecting signal and high positioning accuracy. In this paper, firstly, a complete set of gas pipeline leakage experimental device was built on the basis of stimulus-response method. Secondly, three leakage points were designed and tested to investigate the positioning accuracy. Finally, the impacts of aperture size and incentive intensity on positioning result were evaluated, and the detectable aperture size and minimum incentive intensity were determined. The results show that under fully-closed condition of the terminal valve, the minimum pore size that can be detected is 2 mm in the experimental tests (with an aperture ratio of 4 percent). It is expected that the outcomes can provide reference for improving localization methods of gas pipeline leakage.

Keywords: Gas pipeline; Leakage detection and location; Stimulus-response method

1. Introduction

Pipeline transportation is efficient and economical to transport natural gas from fields to customers. Gas pipeline leakage accidents due to pipeline cracks, corrosion, ageing, and third-party interference not only result in energy waste, environmental pollution and economic loss, but also threaten people's life and property seriously so that reliable and timely leakage detection of pipelines is indispensable for gas transportation [1]. In China, the work toward leakage detection is only at the beginning stage. The total length of gas pipelines has increased significantly in recent years in China, and pipeline leakages occur more and more frequently [2]. So, there is of extremely vital significance to find an efficient way to detect the leakage quickly and locate the leak position accurately.

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In this study, a laboratory bench was built to evaluate the accuracy of the stimulus-response method. Furthermore, the impacts of aperture size and incentive intensity on positioning result were evaluated, and the detectable aperture size and optimum incentive intensity were determined.

2. Experimental system and leakage localization principle

2.1. A brief introduction of the experiment system

Fig.1 illustrates the experimental setup in this study, which fundamentally consists of pipelines, valves, flow meters, pressure transmitters, an air compressor and two tanks. The total pipeline length is 14 meters with an internal diameter of 50 mm. The pipeline is constructed of steel to ensure the maximum pressure of the system to 2.0MPa. For security consideration, the actual gas flow was simulated by air flow, and the steady flow was formed due to a pressure difference between the gas tanks. Air compressor was set to increase the pressure of gas tank E1 by inflating it. Pressure transmitters, orifice plate flow meters and other equipment were installed at both ends of the pipeline.
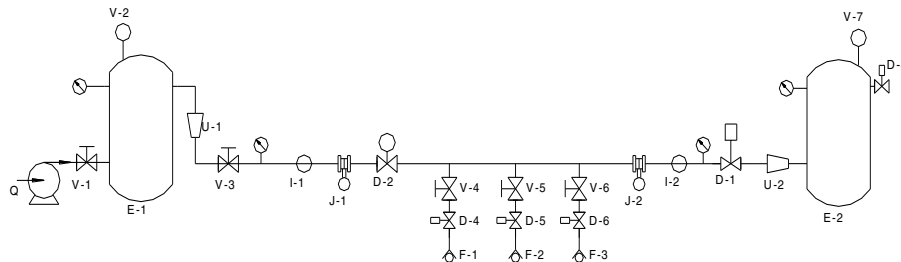
Q—air compressor；E—gas tank；I—pressure transmitter；U—pressure regulating valve；
V—ball valve；J—orifice plate flow meter；F—rotor flow meter；D—solenoid valve；

Fig.1 Schematic diagram of experimental setup

Three leakage points (V-4, V-5 and V-6) were located at 10m, 7m and 4m away from the terminal pressure transmitter, respectively. The leakage process was simulated by combining the manual ball valves and solenoid valves, in which rotor flow meters (F-1, F-2 and F-3) are used to measure the amount of leakage at leakage point, and the ball valves (V-4, V-5 and V-6) are set to control the amount of gas leakage, and the solenoid valves (D-4, D-5 and D-6) are installed to realize the instantaneous occurrence of the leakage. Leakage locations could be determined by the stimulus-response method by switching the terminal solenoid valve (D1) on and off.

2.2. Testing principle and procedures

All the valves on the pipeline were closed before the experiments. Valve V-1, V-3 and D-2 were opened after the experiment commenced. The open degree of D-2 was set at 30°. Then the air compressor Q was started to aerate gas tank E1, and turned off when the pressure reaches 0.4MPa. After 10 minutes, the solenoid valve D1 was opened to produce a transient flow from gas tank E1 to gas tank E2. After the transient flow was formed, valve V-5 was regulated to full open position and kept about 1 minute until the transient flow approached steady state. At this time valve D-5 was turned on to produce a leakage. Then the solenoid valve D1 was suddenly closed to form a stimulus wave. The terminal pressure data were collected by the pressure transmitter. The leakage conditions of valve V-4 and V-6 were also tested.

Stimulus wave transmit from the terminal to the starting point of the pipeline is assumed to travel at the same speed as sound does. When arriving to the leakage point, pressure difference between the outer and inner spaces of the pipeline experiences a rapid change, and the generating response waves (δp) start to move to the terminal. Meanwhile, the stimulus wave decreases by a scope of δp, and then goes on

travelling upstream. The terminal pressure transmitter collects the pressure signals. Supposing that the time difference between stimulus wave and response wave at the pressure transmitter is *Δt,* the distance between the leakage point and the terminal pressure transmitter is calculated by the following formula:

$$x=a*\Delta t/2$$

Where x is the distance between leakage point and terminal pressure transmitter (m) and a is stimulus wave velocity (m/s).

3. Localization results

The experimental results from the stimulus-response method were reflected by the pressure fluctuation curve at the point of terminal pressure transmitter as shown in Fig.2.
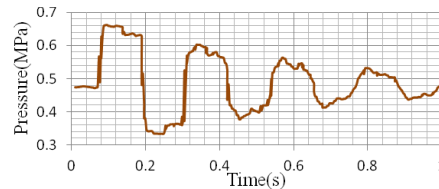

Fig.2 Pressure fluctuation curve at terminal pressure transmitter

The stimulus wave passed the terminal pressure sensor by at 0.082s, resulting in a pressure rise from 0.475 to 0.660Mpa. And at 0.126s, when response wave passed by, there was a sudden drop of pressure from 0.651 to 0.634MPa. The time difference is 0.044s, the distance between the solenoid valve and the leakage point is 7.48m according to formula 1, and the localization error is 6.86%. Table 1 presents the localization results and errors at the three leakage points (D3~D5).As illustrated in Table 1, the relative error is related to the distance between the leakage point and the pressure transmitter; the larger the distance, the higher location accuracy.

Table 1 Localization results of three leakage points

Point	Actual distance (m)	Time difference (s)	Detection result (m)	Relative error (%)
D3	4	0.025	4.33	8.25
D4	7	0.044	7.48	6.86
D5	10	0.062	10.54	5.4

4. Influence of leakage aperture size on stimulus-response method

In the stimulus-response method, sometimes, it is difficult to capture the response wave by the pressure transmitter, as the leakage aperture is extremely small. To investigate the influence of leakage amount on location result, the leakage aperture was set to be 1mm, 2mm, and 5mm, respectively, by adjusting the ball valve V5 to corresponding open degrees. The result curves are illustrated in Fig. 3. The bigger the leak aperture, the easier the leak result can be observed, and the faster the wave declines.

When the leakage aperture is 1mm (with the aperture ratio of 2%), the sudden pressure drop caused by the response wave is almost invisible in the curve. The pressure drop of 2mm aperture is more observable, and that of 5mm is clearly visible. The pressure drops of 1mm leak, 2mm leak and 5mm leak are 0.010, 0.013,0.017MPa, respectively. It can be concluded that when the leakage aperture size is bigger than or equal to 2mm (the aperture ratio is equal or bigger than 4%), the leakage can be judged by the terminal pressure curve, namely the leak condition can be located by the stimulus-response method.

5. Influence of stimulus wave size on stimulus-response localization method

When the leakage aperture size is constant, the higher the intensity of stimulus wave, the bigger the pressure decrease at the leak point, and the easier the leak can be detected. In the experimental test,

stimulus wave's intensity is controlled by regulating the terminal solenoid valve to different close degrees. Fig.4 shows the terminal pressure oscillation curves under conditions of solenoid valve 100%-closed, 75%-closed, and 50%-closed respectively (the leak aperture size is 2mm).When the solenoid valve is 100%-closed, the intensity of the stimulus wave is 0.14MPa; and when the close degree is 75% and 50%, the stimulus wave's intensity is 0.1050MPa and 0.0680MPa respectively. As the valve closed degree drops, the pressure of stimulus waves decreases proportionately.
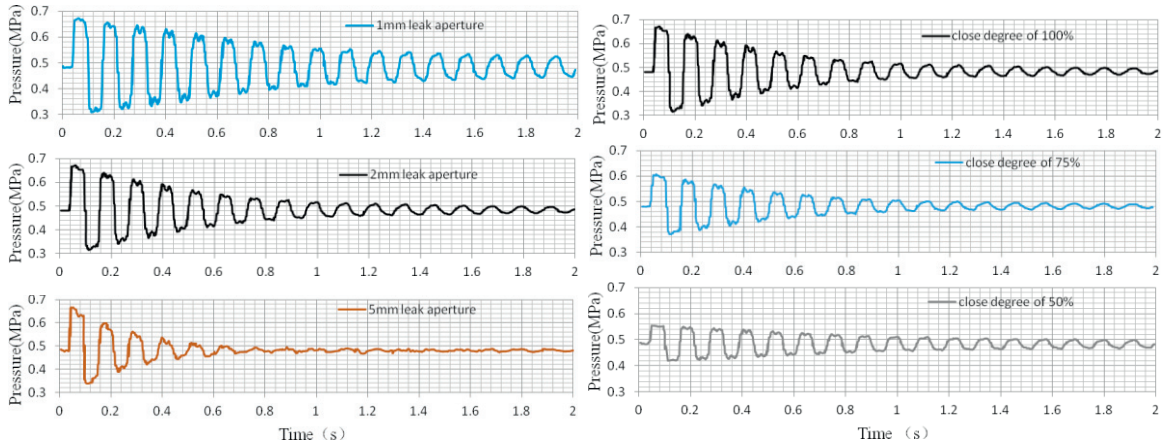
Fig.3 Pressure curves under different leak aperture sizes   Fig.4 Pressure curves under different close degree of stimulus wave

The observability of the response wave decreases along with the close degree of the solenoid valve. When the valve is in the 50%-closed condition, the pressure drop resulted from response wave is completely disappeared on the curve. That is, in the stimulus-response method, when the ratio of leakage diameter and pipeline diameter is 4%, the close degree of the solenoid valve should be no less than 75%.

6. Conclusions

Employing the stimulus-response method, an experimental setup was built, and the relative errors of locations at 10m, 7m and 4m are 5.4%, 6.86% and 8.25%, respectively. It is possible to conclude that the larger the distance between the leakage point and the pressure sensors, the higher location accuracy we can get;

Under the condition of terminal valve fully closed, leakage localization can be processed when the aperture ratio is greater than 4%. For aperture ratio less than 2 percent, this approach is not applicable.

The observability of the response wave decreases along with the close degree of the solenoid valve. When the aperture ratio is 4%, the close degree of the solenoid valve should be no less than 75%.

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Biography

Zhang Tiantian received his bachelor and master's degree in Harbin Institute of Technology. Now he is studies a Ph.D. student in HIT and a research assistant in Hongkong Polytechnic University. His research interests focus on HVAC, gas supplying and renewable and sustainable energy technologies.