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Value setting for the rate of pressure drop of automatic line-break control valves in natural gas pipelines

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ABSTRACT

Automatic line-break control valves are widely used to prevent the release of gas in the event of a rupture in natural gas pipelines. The rate of pressure drop (ROD) set point at each valve location is a critical parameter that determines whether or not the valve closes, and this value must be measured over a period of time. If the ROD set point is not appropriate, the automatic line-break control valve may mistakenly shut down or not take timely action. In this study 12 typical natural gas pipeline systems in China were analyzed to evaluate the ROD set point problem, which is associated with automatic line-break control valves. Transient analysis hydraulic software was used to determine the appropriate ROD set point for automatic line-break control valves by simulating 891 different pipeline-rupture conditions and 256 valve-closing conditions. The maximum ROD value over 120 s for each condition was obtained by statistically analyzing the simulation results. Each valve-closing condition was affected by the operating pressure and the gas velocity. As the gas velocity or the operating pressure increased, the maximum ROD value also increased. ROD set points for 12 different gas pipelines have been recommended based on the following principles: the upstream valve shutdown should not sequentially cause a downstream valve shutdown, and the maximum ROD value is over 120 s of the various valve-closing conditions. The value-setting method developed in this study can be applied to other gas pipelines.

1. Introduction

Natural gas pipeline systems employ automatic line-break control valves to close valves and prevent the release of natural gas in the event of a pipeline rupture. When a pipeline ruptures, a large pressure drop occurs and the corresponding rate of pressure drop (ROD) can be observed at the adjacent valve location. The ROD value is measured over a pre-set period of time and is used to determine whether a pipeline rupture has occurred. In China, the ROD settings (including ROD values and their corresponding durations) are usually adopted based on domestic or foreign experiences or on estimated values derived from pipeline steady flow over a long time (Wang and Zhang, 2004; Wang et al., 2013). If the automatic line-break control valves in the entire pipeline use a common ROD setting, the valves may either mistakenly shut down when there is no rupture or not shut down when a rupture occurs. Multiple factors, such as pipeline diameter and length and gas operating pressure and flow rate, complicate the process of determining the appropriate ROD value setting. In addition, the risk of downstream valves shutting down in sequence after an upstream valve has closed makes this problem even more complex. Furthermore, an appropriate ROD setting for the automatic line-break control valve must reflect the accuracy and timeliness of the valve's mechanical action.

Several studies on leak detection in gas pipelines have been reported (Harriott, 2011; Noguerol, 2011; Reddy et al., 2011a, 2011b), as have studies on pipeline ruptures (Lacerda and Elias, 2010; AL-Rasheed et al., 2010; Peekema, 2013; Richards, 2013). However, there are only a few studies on setting the ROD value of automatic line-break control valves (Phan and Sawin, 2012), especially relating to how the value settings might differ between gas pipelines.

In this study, transient analysis hydraulic software (PipelineStudio 3.2.7.5, Energy Solutions International, Houston, Texas,

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USA) was used to determine the proper ROD settings for automatic line-break control valves on actual pipelines. Simulations were conducted of 891 unique line-rupture conditions based on various combinations of rupture locations, operating pressures and rupture diameters. In addition, 256 unique valve-closing conditions were simulated based on various valve chamber spacings and operating pressures. An analysis of the simulation results yielded a maximum ROD value over 120 s for each simulated condition. Then, according to various valve chamber spacings, ROD settings were developed for 12 actual gas pipelines. Lastly, a series of equations relating the maximum ROD value over 120 s to the operating pressure and the gas velocity were developed.

2. Simulated pipeline conditions

A natural gas pipeline typically transports natural gas from a gas field to gas consumers and may contain many compressor stations, gas distribution stations and automatic line-break control valves. The hydraulic simulations conducted in this study were based on a gas pipeline section that consisted of two automatic line-break control valves, as shown in Fig. 1.

The flow in the gas pipe section was assumed to be one-dimensional, and all flow parameters in the pipe cross-section were considered to be homogenous. The boundary conditions of the studied pipe section were the upstream pressure of the pipe section (before the automated line-break control valve) and the downstream flow rate of the pipe section. The ROD values of the upstream and downstream automatic line-break control valves were simulated using the transient analysis hydraulic software PipelineStudio under different pipeline-rupture and valve closing conditions. Twelve gas pipeline cases, as shown in Table 1, were used in this study.

In addition, a variety of hypothetical pipeline-rupture conditions were developed to represent combinations of different operating pressures, rupture diameters and rupture locations for 12 case study pipelines (Table 2). Separately, different valve-closing conditions were developed for the 12 case study pipelines using different operating pressures and valve spacings (Table 3).

Table 2 describes 891 pipeline-rupture conditions consisting of different operating pressures, rupture diameters and rupture locations. Table 3 includes 256 valve-closing conditions consisting of different operating pressures and valve spacings. For example, the #9 gas pipeline system had a diameter of 660 mm, a design pressure of 6.4 MPa and a design throughput of 3×10^9 Nm^3/a. Sixteen valve-closing conditions were simulated, including different operating pressures and valve spacings (Table 4).

3. ROD calculation method

The transient hydraulic simulation software PipelineStudio is capable of calculating instantaneous pressure change with respect to time. Fig. 2 is a graphical representation of the calculated pressure change at a valve chamber 16 km downstream of a 700-mm-diameter rupture in a 1422-mm-diameter gas pipeline system. The design pressure was 12 MPa, and it operated at a pressure range of 6–8 MPa.

To accurately model the line-break control valve pressure, the results from PipelineStudio simulations were exported, and the ROD values were calculated independent of the simulation software. ROD calculations were based on an assumption that the actuator of an automatic line-break control valve was able to record pressure values once every 5 s, as shown in Fig. 3.

The average pressure value at time t can be calculated using Eq. (1):

$$P_{avg,t} = \frac{p_1 + p_2 + p_3 + p_4}{4} \tag{1}$$

where $P_{avg,\ t}$ is the average pressure value at time t s, MPa; p_1 is the pressure value at time t s, MPa; p_2 is the pressure value at time $t-5$ s, MPa; p_3 is the pressure value at time $t-10$ s, MPa; and p_4 is the pressure value at time $t-15$ s, MPa.

The average pressure value at time $t-60$ can be calculated using Eq. (2):

$$P_{avg,t-60} = \frac{p_{13} + p_{14} + p_{15} + p_{16}}{4} \tag{2}$$

where $P_{avg,\ t-60}$ is the average pressure value at time $t-60$ s, MPa; p_{13} is the pressure value at time $t-60$ s, MPa; p_{14} is the pressure value at time $t-65$ s, MPa; p_{15} is the pressure value at time $t-70$ s, MPa; and p_{16} is the pressure value at time $t-75$ s, MPa.

The ROD value at time t is calculated using Eq. (3):

$$ROD = P_{avg,t-60} - P_{avg,t} \tag{3}$$

where ROD is the rate of pressure drop value at time t, MPa/min.

Based on Eq. (3), the ROD values versus time at the downstream valve chamber can be calculated. The maximum ROD value over 120 s was obtained through statistically analyzing the simulation results (Fig. 4).

Fig. 4 shows that the maximum ROD value over 120 s from the rupture described above was 0.22 MPa/min. Consequently, a valve setting of 0.22 MPa/min (or less) over 120 s would detect this rupture.

4. Case study

A 1219-mm-diameter gas pipeline system designed to operate at a gas pressure of 12 MPa (denoted as "1219 mm/12 MPa gas pipeline system", i.e., #2 gas pipeline system in Tables 1–3) is used to illustrate how changes in the maximum ROD values over 120 s were determined for different pipeline-rupture and valve-closing conditions. The 1219 mm/12 MPa gas pipeline system has the same configuration as the second branch of the West–East gas pipeline system in China. The design gas throughput of this pipeline is 30×10^9 Nm^3/a.

In this analysis, the ROD value duration time is 120 s Figs. 5–10 show the maximum ROD values over 120 s with respect to distance

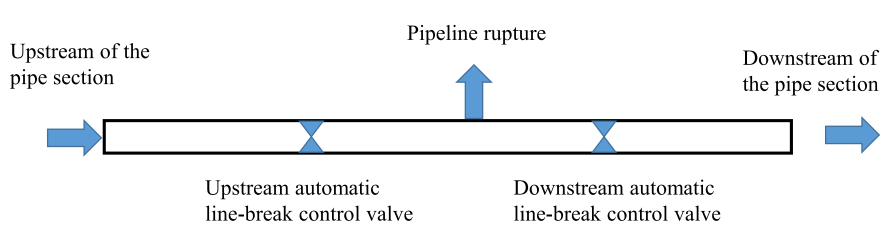

Fig. 1. Schematic diagram of a pipe section.