Journal of Loss Prevention in the Process Industries 31 (2014) 133–141

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

The dynamic response of pressure relief valves in vapor or gas service. Part III: Model validation

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ARTICLE INFO

Article history:
Received 20 September 2013
Received in revised form
19 March 2014
Accepted 8 June 2014
Available online 30 June 2014

Keywords:
Relief valve stability
Chatter
Stability model validation

ABSTRACT

Part I of this series described a mathematical model for predicting the dynamic response and stability characteristics of a pressure relief valve in gas/vapor service, and Part II described an experimental investigation to obtain dynamic response data for various valve sizes from various manufacturers to identify conditions under which instability (chatter) could occur. This paper presents the results of the program, and shows a comparison of the model predictions with the measured dynamic response data, and discusses the information required to implement the model.

1. Background

This is the third of three papers describing a program funded by a consortium of American Petroleum Institute (API) member companies to investigate the factors which contribute to the instability (chatter) of safety relief valves, and to develop a model which could predict the conditions under which the valve would chatter. The first paper, Part I (Darby, 2013), described a mathematical model which predicts the dynamic response (disk lift vs. time) of a spring-loaded direct acting pressure relief valve (PRV) in gas/vapor service, including the conditions under which the response could be unstable. Part II (Aldeeb et al., 2014) described a testing program, conducted at the Pentair Valves and Controls test facility in El Campo, TX, in which valves of three different sizes, each from three different manufacturers, were tested at two different set pressures, both with and without various lengths of inlet and discharge piping. That paper summarized the results of those tests, including examples for which the valves were both stable and unstable upon opening. In this paper, we show the comparison between the model predictions and the measured dynamic response, and a discussion of the parameters required to implement the model.

2. Test results

Three valve sizes (1E2, 2J3 and 3L4) from each of three different manufacturers (designated X, Y, and Z) were tested in the facility described in Part II of this study (Aldeeb et al., 2014). The dynamic response (disk lift vs. time) was measured for each valve at 50 and 250 psig set pressure. The valves were tested with 0, 2, 4, and 6 ft of inlet piping, and the two larger valves were also tested with discharge piping attached. Table 1 summarizes the results of the tests on all valves with inlet piping flowing at rated flow capacity. A few of the 2J3 and 3L4 valves are listed as “not tested” because these valves had been previously tested under reduced capacity conditions and had apparently suffered some damage in these preliminary tests so as to make them unreliable for further testing. It is noted that all valves showed stable operation with no inlet piping and with 2 ft of inlet piping. Also, the tests on all valves at 50 psig set pressure showed stable operation with one exception. The effect of discharge piping was also evaluated for the larger (2J3 and 3L4) valves with 50 psig set pressure. The 2J3 and 3L4 valves were tested with discharge pipe lengths of 31.4 ft and 17.9 ft, respectively. The tested discharge piping lengths resulted in a pressure drop in the discharge line of approximately 8–9% of set

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http://dx.doi.org/10.1016/j.jlp.2014.06.001
0950-4230/

Table 1
Summary of the stability response of all valves flowing at 100% capacity and all inlet piping configurations.

Manufacturer	Valve size & set pressure	Inlet piping length			
		0 Feet	2 Feet	4 Feet	6 Feet
X	1E2 – 50 psig	Stable	Stable	Stable	Stable[a]
	1E2 – 250 psig	Stable	Stable	Unstable	Unstable
	2J3 – 50 psig	Stable	Stable	Stable	Unstable
	2J3 – 250 psig	Stable	Stable	Not tested	Not tested
	3L4 – 50 psig	Stable	Stable	Stable	Stable
	3L4 – 250 psig	Stable	Stable	Stable	Not tested
Y	1E2 – 50 psig	Stable	Stable	Stable	Stable
	1E2 – 250 psig	Stable	Stable	Unstable	Unstable
	2J3 – 50 psig	Stable	Stable	Stable	Stable
	2J3 – 250 psig	Stable	Stable	Not tested	Not tested
	3L4 – 50 psig	Stable	Stable	Stable	Stable
	3L4 – 250 psig	Stable	Stable	Not tested	Not tested
Z	1E2 – 50 psig	Stable	Stable	Stable	Stable
	1E2 – 250 psig	Stable	Stable	Stable	Stable
	2J3 – 50 psig	Stable	Stable	Stable	Stable
	2J3 – 250 psig	Stable	Stable	Not tested	Not tested
	3L4 – 50 psig	Stable	Stable	Stable	Stable
	3L4 – 250 psig	Stable	Stable	Unstable	Not tested

[a] This test has been repeated two times. In the first test run, the valve exhibited a stable lift. However, in the second testing run, the valve went into unstable lift response.

pressure. These results are shown in Table 2. The discharge piping had no effect on the stable operation of the valves, and only a minor effect on the dynamic response characteristics.

3. Model parameters

The mathematical model for the dynamic response of the valve (e.g., disk lift vs. time) was described in Part I of this series (Darby, 2013). The input parameters required to implement the model are listed in Table 3. These parameters are classified into three groups: process conditions, valve specifications, and installation parameters. The process conditions include the properties of the fluid (assumed to be an ideal gas), inlet and discharge temperatures and pressures and the specified relief mass flow rate (calculated at 110% of relief set pressure). The valve specifications include the set pressure, overpressure, blow-down pressure, nozzle diameter, discharge coefficient and the various physical characteristics of the valve, including the mass of moving parts, spring constant, open and closed disk contact diameter, and three parameters listed as "not available": the damping factor and two fluid deflection angles. These three parameters are discussed below. The installation parameters are the length and (inside) diameter of inlet and discharge piping, volume of gas/vapor space in vessel and inlet piping, loss coefficient for fittings and the Fanning friction factor for inlet and outlet piping. Although standard references can be consulted for typical friction factor values, it is recommended that for accurate work these be measured independently (in this study, the measured friction factors deviated significantly from the "textbook" values (e.g., from 0.0040 to 0.0055 for the 1-in. to 3-in. pipe), as reported in Part II of the study. The inlet fitting loss coefficient of 0.2 was calculated for the rounded nozzle entrance from the test tank based on measured pressure loss.

3.1. Damping factor

The damping factor (ζ) represents the resistance to the motion of the moving parts when the valve opens, and is not readily measured or easily determined. It is influenced by such factors as the degree of lubrication of the spindle, alignment of shaft and spindle, contamination (dirt, rust, etc.), possible damage to shaft or spindle from metal–metal contact during opening, etc. Hence it tends to vary not only from valve to valve but also with operating conditions. Thus, no independent values are available for this parameter so it is considered a "model fitting parameter" determined by adjusting the value to give the best fit of the model output to the data.

3.2. Deflection angle

With reference to Fig. 1, the deflection angle (θ) represents the angle (measured downward from the horizontal) of the fluid stream as it departs from contact with the disk. This angle is a key

Table 2
Summary of tests of valves at 100% flow capacity with inlet and discharge[a] piping.

Manufacturer	Valve size & set pressure	Inlet piping length					
		2 Feet		4 Feet		6 Feet	
		Valve initial lift stability		Valve initial lift stability		Valve initial lift stability	
		Model prediction	Actual test	Model prediction	Actual test	Model prediction	Actual test
X	2J3 – 50 psig	Stable	Stable	Stable	Stable	Unstable	Unstable
	3L4 – 50 psig	Stable	Stable	Stable	Stable	Stable	Stable
Y	2J3 – 50 psig	Stable	Stable	Stable	Stable	Stable	Stable
	3L4 – 50 psig	Stable	Stable	Stable	Stable	Stable	Stable
Z	2J3 – 50 psig	Stable	Stable	Stable	Stable	Stable	Stable
	3L4 – 50 psig	Stable	Stable	Stable	Stable	Stable	Stable

[a] For the 2J3 and 3L4 valves, the tested discharge piping lengths were 31.42 feet and 17.92 feet, respectively.