An Engineering Method to Mitigate the Impact of Regulatory Focus on Relief System Installations by Prioritizing Risk

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Abstract

Since around 2005, regulators in the United States have put greater emphasis on relief device installations meeting the 3% rule. Spending large amounts of money to "fix" relief device installations that pose no safety risk decreases the plant's overall safety. To date, more incidents have occurred during facility construction / modifications than due to relief device chatter. This paper presents a method to assist engineers in determining if relief devices are susceptible to chatter. The methodology in this paper provides an engineering study to determine if existing installations are safe, which are allowed in the relevant engineering standards (API STD 520), and shows the research data by which it was validated. The model is used as a screening method that places the relief devices into two categories: (1) those installations that may chatter and (2) those installations that need no further review. The goal of any experimental comparison is that the model will error on the side of predicting chatter, but will be reliable enough to screen valves.

In addition to presenting the model, this paper will compare instances of known chatter to research conducted by API and work done by the Electric Power Research Institute in the 1980s. Thus far, based on research and acquired information, the method predicted all instances of chatter known to the authors. By providing a screening methodology that is supported by experimental data, plants can focus their spending on fixing real safety issues by identifying which relief installations are not expected to chatter. The paper will close by giving a brief explanation of the on-going research in relief valve stability.

1. Introduction

In November 2011, *Hydrocarbon Processing* published a paper that documented a method to determine if relief devices were susceptible to chatter. Other methods are being developed to determine the chances of chatter for a specific installation; however, the model discussed in the published paper is the only screening method that places the relief devices into two categories: (1) those installations that may chatter and (2) those installations that need no further review. The goal of any experimental comparison is that it will error on the side of predicting chatter, but will be reliable enough to screen valves. Since the publication of that article, the Oil & Gas industry has continued to struggle with the issue of relief device stability, so much so that API delayed issuance of *API STD 520 Part II Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries-Part II, Installation*. This paper compares instances of known chatter to research conducted by API, and uses this comparison to evaluate the model. Thus far, based on research and all acquired information, the method predicted all instances of chatter known to the authors.

This paper summarizes the analysis methods and validation for vapor service valves. The November 2011, *Hydrocarbon Processing* paper documents analysis methods for two-phase and liquid services. The focus on vapor / gas service valves is based on the validation data for these services analyzed herein.

2. Summary of the Stability Screening Method

The following is a summary of items used to confirm if chattering is likely to occur. Refer to the published paper for an extensive discussion of the methodology:

1. Confirm that the inlet line length is within the criteria to ensure that the pressure wave decay is not high enough to cause valve instability. The following equation (from Frommann & Friedel, Source 4) is used for this criteria:

$$L_i < 45{,}390\frac{d_i^2}{w_{\%O}}\left(\frac{P_S - P_{RC}}{P_S}\right)\left(P_S - P_B\right)t_o \qquad \textbf{Equation 1}$$

2. Confirm that the system's frictional and acoustic losses are less than the difference between the operating pressure and the valve's closing pressure. The formula for estimating the acoustical losses (from Singh, Source 5) is presented below:

$$\Delta P_{Acoustic} = \frac{Lw_{PSV}}{12.6d_i^2 t_O} + \frac{1}{10.5\rho}\left(\frac{w_{PSV}L}{cd_i\, t_O}\right)^2 \qquad \textbf{Equation 2}$$

3. Ensure that stability will not be compromised due to vortex shedding in the inlet line (this phenomenon occurs during normal operation and is generally not associated with relief conditions).

$$L_i < \frac{d_i c}{2.4U}$$ **Equation 3**

4. Ensure that the relief rate or system size is at sufficient capacity to confirm that chattering will not occur from being oversized. For vapor service relief devices, this is assumed to not occur if the open-close cycle time for the system is greater than 1 second. This cycle is broken into two components: the time it takes for the system pressure to increase from the relief devices' blowdown/closing pressure to the set pressure and the time it takes for the system to depressure through the relief valve from the set pressure to the blowdown/closing pressure. This is represented by the following equation.

$$1 > t_{cycle} = t_{P_{RC} \to P_S} + t_{P_S \to P_{RC}}$$ **Equation 4**

5. Ensure that the relief device is installed per the manufacturers' and/or general installation guidelines. These guidelines are shown in the catalogs, ASME B&PVC Section VIII, API STD 520, etc.

6. Review the valve's operational history to ensure that there is no known history of chatter.

For a complete discussion on the methodology of this analysis, the reader is referred to the work published by Smith Et. al, as the discussion is not further expanded in this paper.[1] Note that equation 17 does not follow the verbiage, and the *less than* sign should be replaced with a *greater than* sign.

3. Acceptance Criteria

This model is the only screening method to place the relief devices into two categories: (1) those installations that may chatter and (2) those installations that need no further review. The goal of any experimental comparison is that it will error on the side of predicting chatter, but will be reliable enough to screen valves. The author considers this model to be reliable as an engineering screening tool if the following criteria are met:

- *High Correlation to Experimental Data* – If the method predicts that valves will chatter and valves won't chatter most of the time, then it is a viable screening tool given the low cost of performing the analysis compared to making piping modifications.

- *No False Negatives* – The screening tool will be considered valid so long as it does not predict any installations as safe (no chatter) when in fact chatter was experimentally found.
- *Limited False Positives* – Given that the method is a conservative screening tool, some level of false positives are to be expected. This includes instances when the model would indicate the possibility of chatter when experimental results show valve stability.
- *Screens Valves as Acceptable* – The model will only be of value if the results of the model result in existing installations not requiring further modification. Based on the results presented in the referenced paper, 50% of the installations with inlet pressure losses greater than 3% were deemed acceptable as is.

The model, therefore, will be deemed conservative and reliable if the previous four criteria are met.

4. Comparisons / Validations

To confirm the validity of the procedure, the procedure has been reviewed against all cases of chatter known to the authors. The cases are divided into three different categories:

1. ***Known Installations*** – These installations are those that are known by the authors to have failed with a loss of containment and those installations that have sufficient information to perform the analysis. The information for some of the installations is not available in the public domain, as the confidentiality of these installations has been preserved.
2. ***ASME Studies*** **–** In the 80's, Zahorsky performed a set of research for the nuclear industry in which they experimentally set the blowdown as the minimum percentage needed for stable operation[2]. In order to meet the acceptance criteria, therefore, this method should determine that these installations are unstable. The results were re-checked with an increased blowdown of 2% above what the author listed to see what would happen.
3. ***API PERF Studies*** **–** In 2011 the results of the API PERF study were presented at the API 520 Committee meeting. In this work, the API subgroup tested 18 different valves with three different inlet line lengths to determine when chatter would occur. The results of the 54 trials were introduced in their presentation (some combinations were not tested).

5. Results

The following are the results of the comparisons:

Table 1 lists the results of the model comparison with the valves that have had a loss of containment where inlet line chatter was the cause or a contributor to the incident. The model predicted the potential for chatter for each of these installations.

Table 1: Summary of known installations that have chattered

Installation	**Service**	**Chatter Predicted**	**Data Source**
Refinery, North America	Liquid	Yes	Internal company incident investigation
Gas Plant, Middle East	Vapor	Yes	Internal company incident investigation
Refinery, North America	Liquid	Yes	Internal company incident investigation
Refinery, North America	Liquid	Yes	API Published Document [3]

Table 2 lists the blowdown at which the relief devices do not chatter as experimentally determined by Zahorsky. The table also lists the blowdown at which the model would predict stability. The difference between the two values can be taken as an estimate to which the model is conservative. Since the blowdown was experimentally set as the minimum percentage, the model is accurate, as it predicts false positives for these devices.

Table 2: Comparison of minimum predicted blowdown to the results experimentally derived by Zahorsky

Run Case	**Experimentally Determined Blowdown**	**Predicted Acceptable Blowdown**	**(Δ Blowdown) Predicted – Expermintal)**
1	3.9%	4%	0.1%
2	3.9%	5.6%	1.7%
3	5.6%	9.7%	4.1%
4	8.4%	16.7%	8.3%
5	8.3%	12.6%	4.3%
6	4.3	5.3	1.0%

Table 3 lists the comparison of the model results to the experimental PERF results. The model had agreement ~72% of the time if the cases that were not tested were excluded. If one assumes that the results for the untested cases would have chattered, the agreement is ~76%. Of the cases that the model did not agree with the experimental results, the model always predicted chatter on stable valves; thus, the model is accurately screening and is slightly conservative.

Table 3: Comparison of the model to the API PERF Study Results

Model Correlation	PERF Results	Model Prediction	No. Of Cases
Agreement	Chatter	Chatter	9
Agreement	Stable	Stable	25
False Negative	Chatter	Stable	0
False Positive	Stable	Chatter	15
Agreement[1]	Not Tested	Chatter	7

Note 1: There are a number of cases that were not tested, but were assumed to chatter as the reason for not being tested was not included.

6. Conclusion

The model results always predicted when valves may chatter (need modifications). There are no instances of valves that have chattered where the model predicted stability.

- *High Correlation to Experimental Data* – There is a 70% to 75% agreement with the API PERF Studies and all industry installations with known chatter where identified with the model. This model predicted if a valve would chatter accurately 75% of the time (see the next item on false negatives).
- *No False Negatives* – No cases of chatter were found when the model predicted stable operation.
- *Limited False Positives* – 25% of the PERF study valves that were stable indicated that chatter was possible. Also, the work by Zahorsky indicated that the model predicts stable operation with an inlet blowdown generally 2% to 4% greater than needed.

The model, therefore, is a reliable method to screen relief devices based on the comparison to 60+ experimental and industrial data points.

7. Notation

The equations presented in this paper are dimensional and the following listing explains the variables and unit set.

c = speed of sound (ft/s)
d = diameter (in)
L = length (ft)
P = pressure (psig)
t = time (s)
U = process fluid velocity as it passes the PSV nozzle (ft/s)
w = mass flow rate (lb/s)

Greek Letters

ρ = fluid density (lb/ft^3)

<u>Subscripts</u>
B = backpressure on relief device
i = inlet
o = opening
PSV = process safety valve
RC = valve reclosing pressure
S = relief device set pressure
%O = flow rate at the valves percent open

8. References

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