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Optimization of recertification intervals for PSV based on major accident risk

Peter Okoh [a,*], Stein Haugen [b], Jan Erik Vinnem [b]

[a] Department of Production and Quality Engineering, Norwegian University of Science and Technology, NO 7491 Trondheim, Norway
[b] Department of Marine Technology, Norwegian University of Science and Technology, NO 7491 Trondheim, Norway

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ABSTRACT

Overpressure is a major hazard in the process industry with the potential to lead to a major accident. Pressure Safety Valves (PSVs) are often used as the last layer of protection against such a hazard and require regular recertification in order to be dependable. The valve safely vents gas from a vessel when the pressure becomes excessive. It is often the practice in industry to apply one or two years as the normal recertification interval of PSV. However, experience from the Norwegian oil and gas industry is that the recertification process several times have caused leaks of gas. The process thus represents a certain risk in itself and the question is then whether the recertification intervals presently being used actually are optimal from a risk point of view? The objective of this paper is to look into this problem, applying typical data from an oil and gas installation. An optimal recertification interval will be calculated based on minimization of risk to personnel.

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1. Introduction

The major accident risk in oil and gas industry may be defined as the risk associated with an unexpected event (e.g. a major leak/release, explosion, fire or structural failure), causing or having the potential to cause serious harm to humans, assets or the environment (Comlaw, 2007; EC, 2005; HSE, 1992; OGP, 2008; PSA, 2015; USEPA-OSHA, 1996). The causes of major accidents vary among the various types of accidents. In the case of major releases and explosions, one of the possible causes is overpressure, either caused by applying too high pressure to a vessel or due to increased temperature as a result of flames impinging on a vessel, section or pipe. This scenario is applicable to pressurized vessels and systems, e.g. separators.

To protect against this scenario, it is the usual practice to install Pressure Safety Valve (PSV) as a proactive barrier against overpressure. Since valves are subject to failure mechanisms such as blockage, corrosion and damage, regular recertification is required to ensure that they are able to fulfill the specified safety function. Recertification encompasses the removal of the PSV from the plant, testing/overhauling it in a workshop, putting it back in place and reporting. The problem with this is that the process of removing it and replacing it implies a certain possibility of a leak occurring (Vinnem et al., 2016; PSA, 2015).

The safety-critical failure modes associated with a PSV include fail-to-open and external leak (Darby, 2013; Hellemans, 2009; Rausand and Høyland, 2004; Rausand, 2014; Vinnem et al., 2016). Safety criticality defines the potential of the failure to pose serious risk to the workers, the environment or the installation. Fail-to-open will imply that overpressure in the vessel being protected by the PSV is not relieved (and may lead to explosion), whereas external leak implies a possibility of ignition and explosion. Other failure modes exist, which are not safety-critical (Hellemans, 2009; Rausand and Høyland, 2004; Rausand, 2014). However, some of these failure modes may affect quality in relation to the production process.

Considering how critical PSV is to safety, recertification is an important means to ensure acceptably low probability of failure on demand. However, since statistics show that leaks can occur in this process, the frequency of recertification becomes a matter of optimization. If the PSV fails to relieve overpressure when required, a serious release of gas/oil may occur and if this is ignited serious loss of life may occur. On the other hand, the recertification can lead to a leak which again may ignite and cause loss of life. This is a problem that is well suited for optimization, by finding the recertification interval that gives the lowest total risk of loss of life.

* Corresponding author.
E-mail address: peter.okoh@ntnu.no (P. Okoh).

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It is often the practice in industry to apply one or two years as the normal recertification interval of PSV. However, how can we be certain that this interval is optimal for a given case? Reliability-based (usually cost-related) and risk-based approaches exist for optimizing the interval at which an item should be maintained. However, the current practice is such that increased risk during recertification (e.g. in relation to leak) is often unaccounted for in the determination of recertification interval, whereas consideration is being given only to the reduced risk after recertification (Vinnem et al., 2016). In other words, existing optimization methods do not account for PSV-recertification-induced-leak, but only other failure modes (Chien et al., 2009; Maher et al., 1988).

In this paper, the main objective is to apply a method that directly optimizes with respect to risk to people, taking into account the safety-critical failure modes "fail-to-open" and "PSV-recertification-induced leak", thus accounting for the influence of recertification within the period after and during recertification.

This paper is delimited to focus on safety-critical failures of PSV, including its relationship with pressure vessels, in gas application in the hydrocarbon industry. It is also delimited to a situation whereby the plant is shutdown for PSV recertification. The rest of the paper is structured as follows. First, existing optimization methods will be reviewed. Second, further investigation on PSV recertification will be presented, including the situation in Norway and the effects of changing recertification interval. Third, a case study will be presented in relation to the selected optimization methodology. Fourth, there will be some discussion on the results. Finally, a conclusion will be drawn.

2. Review of existing methods for the optimization of maintenance interval

Optimization of maintenance interval with respect to maintenance costs while safety is kept as a constraint has been studied by many authors. The early methods focused on test interval optimization based on minimizing the time-average unavailability without considering cost (Jacobs, 1968; Hirsch, 1971; Signoret, 1976; Vaurio, 1991). This approach was later extended to optimization based on cost with safety primarily being a constraint (Vaurio, 1995; Vatn et al., 1996; Dekker, 1996; Vaurio, 1997; Vatn, 1997) and optimization based on equipment risk without consideration for risk to humans (Vaurio, 1995; Jo and Park, 2003; Khalaquzzaman et al., 2010, 2011; Kančev and Čepin, 2011a,b). Cost-based optimization is being widely applied in industrial engineering and features as a step in the RCM (Reliability Centered Maintenance) process, where it is used to optimize the maintenance interval after a suitable maintenance task would have been selected with the RCM decision tree (Rausand and Vatn, 2008). In addition, cost-based optimization has also found application in the concept of maintenance grouping for setup cost-saving (Wildeman, 1996; Wildeman et al., 1997; Vatn, 2008; Nicolai and Dekker, 2008; Hameed and Vatn, 2012) and major accident risk management (Okoh, 2014, 2015).

Reason (1997) highlights the effect of the amount of direct contact between people and the system. Such contacts constitutes the greatest human performance problem in most high-risk industries where frequency of contact can be seen as a greater error opportunity. The likelihood of error is further analyzed together with neglected maintenance to explain the risks they posed to the system. Besides, the safety-criticality of items is a key contributor to the motivation for high level of maintenance contact (which implies high level of exposure of personnel). As regards optimization to justify the rationale for preventive maintenance, Reason (1997) suggests a graphical approach (Cost vs. Level of maintenance plot) whereby the optimal level of preventive maintenance is determined by combining the cost of both preventive and corrective maintenance and then selecting the level that coincides with the lowest overall maintenance cost (Reason, 1997).

Optimization of maintenance interval with respect to risk has also been in existence. Apeland and Aven (2000) consider one of the main challenges to be the need for comparing options described through different system attributes, i.e. performance measures related to different categories, like fatality, environmental damage and economic loss. They mentioned the possibility of prioritizing these attributes via a weighting system (Apeland and Aven, 2000). Vaurio (1995) demonstrated risk-based maintenance optimization, considering risk to equipment only.

Some literature support the concept of risk-based optimization with consideration for risk to humans. According to Evans and Thakorlal (2004), following the Piper Alpha disaster in 1988, the issue of maintenance personnel exposure has resulted in a paradigm shift in the design of unmanned platforms. Post-Piper Alpha designs for such installations usually omit firefighting systems, e.g. fire pumps, based on the reason that the risk reduction benefit they offer to maintenance personnel is not commensurate with the frequency of visits of the personnel unlike in a manned facility (Evans and Thakorlal, 2004). In other words, fire pumps are considered to offer a negative risk contribution to an unmanned platform, due to increased need for visits by maintenance personnel.

A human-risk-related preventive maintenance problem has also been studied earlier in The Netherlands, where the focus is on scheduling maintenance to prevent fatalities due to unmanageable railway track maintenance workload at night (van Zante-de Fokkert et al., 2007).

Regarding direct focus on PSV, some existing literature have also been seen. Cost-based optimization in relation to reliability has been proposed (Maher et al., 1988). Furthermore, variations to reliability and risk-based approaches have been suggested, which include, the determination of recertification interval by considering a PSV's reliability/risk data as corresponding to one of some categories of reliability/risk-based inspection criteria and then suggesting a corresponding maintenance interval (Chien et al., 2009; Hellemans, 2009).

Concluding, existing approaches tend to focus on the least cost of doing recertification per unit time such that the existing risk acceptance criterion is satisfied (i.e. a reliability, cost-based approach) or the least frequency of doing recertification such that the equipment experiences the least possible risk of damage (i.e. an equipment, risk-based approach). In relation to the objective of this paper, the latter being more relevant to the objective of this paper, needs to be adapted to cover also human risk.

3. Further investigation on PSV recertification

3.1. *PSVs in the Norwegian petroleum industry*

PSVs are self-contained and self-actuating pressure relief devices. According to American Petroleum Institute (API), a pressure relief device is the general term for a device designed to prevent pressure or vacuum from exceeding a predetermined value in a pressure vessel by the transfer of fluid during emergency or abnormal pressure conditions. Pressure relief devices include reclosing relief devices (e.g. PSVs) and non-reclosing relief devices (e.g. rupture disc or buckling pin devices). PSVs must operate within the specified limits according to international codes and standards (e.g. EN/ISO 4126, API 527 etc) and this includes closing at a predetermined pressure when the system pressure has dropped to a safe level.

The primary purpose of a PSV in a process plant is the final

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