Safety and reliability improvements of valves and actuators for the offshore oil and gas industry through optimized design

by

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Abstract

Valves are essential components of piping systems in the oil and gas industry, especially offshore, where they are used for stopping or starting the fluid, flow regulation, and back flow prevention, as well as safety reasons. The efficiency, safety and reliability of an oil and gas plant is largely dependent on the handling and transportation of fluid through the piping system, including industrial valves. In the offshore sector of the oil and gas industry, valve failure for different reasons, such as corrosion and material failure, inadequate strength against loads, nonconformance to the international standards, etc., is a big risk, with severe negative consequences. Some of the negative impacts of valve failure in the oil and gas industry, especially the offshore sector, can be summarized as loss of asset and production and Safety and Environmental issues (HSE), including problems like environmental pollution, loss of human life in some cases and jeopardizing safety and reliability, etc. Thus, developing methods to improve the design, selection, safety and reliability of valves and actuators is essential and the main objective of this thesis. It should be noted that actuators are mechanical devices installed on the valves, and the performance of the valves is largely dependent on the actuators.

The literature review mainly focuses on existing tools, including international and Norwegian standards, books and publications for piping and valves in the oil and gas industry. The key findings in the literature review are the identification of different corrosion mechanisms and material choices in the offshore industry; valve technology; applications, design and selection philosophy; different methods for systematic material selection; and International and Norwegian codes and standards for the design of piping and valves.

The basic research carried out is represented by 19 published papers by the American Society of Mechanical Engineering (ASME), Springer and other American journals. Different cases related to the valves and actuators in the Norwegian offshore industry and recent projects, including the Johan Sverdrup project which I was involved in while working for AkerSolutions, have been reviewed in the submitted papers. The data analysis in most of the papers is quantitative, based on calculations and formulas given in international standards such as ASME to improve design, reliability and reduce the weight of the valves. Different key findings, such as subsea valve and actuator safety and reliability improvement through testing, optimized material selection for subsea valves, optimized valve and actuator selection, as well as valve design and weight improvements, have been included in this thesis.

Keywords: Valve, Design, Material, Corrosion, Safety and reliability, Actuator, Offshore, Oil and Gas

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1. Introduction

1.1 Background

Valves are essential components of piping systems and are used for stopping or starting the flow inside the piping, fluid regulation, preventing the back flow and for safety reasons (Nesbitt,2007). Industrial valves' failure to function is a big risk and a costly phenomenon in the offshore sector of the oil and gas industry, with severe negative consequences such as loss of asset, loss of production due to plant shutdown, loss of human life in some cases, and Health, Safety and Environment (HSE) problems like environmental pollution. Different types of industrial valve failure are associated with corrosion and material failure, mechanical failure due to the loads and stresses, and poor design and selection. As an example, the offshore environment contains a chloride-containing marine atmosphere that can cause severe corrosion on offshore facilities such as valves. Figure #1 shows three pictures from left to right related to the corrosion of a valve gearbox and valve bolt, as well as valve body, in recent Norwegian offshore projects. The pictures visualize the corrosion attack on carbon steel materials. Paper #1 provides a literature review and guidelines for material selection of the valves in the subsea sector of the oil and gas industry. Paper #15 provides a model for calculating corrosion allowance due to carbon dioxide for carbon steel piping and valves. Carbon dioxide is an undesirable by-product of oil, causing metal loss or sweet corrosion in the facilities, including the valves.

Figure 1: Corrosion of carbon steel valve / valve components

The other material failure due to operational problems is known as cavitation, which is common in globe valves (Merrick 2015; Sotoodeh 2016). Figures #2 and 3 illustrate cavitation damage, which is in the form of pits on the plugs of globe valves. This problem, and possible solutions to tackle it, have been addressed in Paper #3. One solution to minimize the risk of cavitation as a sort of metal erosion for the valve internals is to select a new generation of valves for flow control, which are known as axial valves. In addition, API 623 was released in 2013 to mitigate the cavitation risk in the valves through the design and selection of a more robust valve (Merrick 2015; American Petroleum Institute 2013). A robust valve means one with a hard facing on the valve internals and a stronger connection between the valve disk and the stem (Merrick 2015; American Petroleum Institute 2013; Sotoodeh 2016).

Selecting and designing lighter valves is more important offshore than onshore, since the heavier weight of valves means greater loads on the platforms, jackets or subsea modules such as manifolds, and it is more difficult and challenging to transport a heavier platform or subsea module. Valve design could contribute to improving safety and reliability. Paper #2 proposes using calculations methodology, as well as finite element analysis, as per ASME Sec. VIII Div.02 rather than ASME B16.34, as a part of the valve design method for pipeline valves, to reduce their weight significantly, ensuring the safety and reliability of the valve during operation to prevent its failure due to various applied loads (American Society of Mechanical Engineers 2004 &2012). Paper #14 provides a justification for the use of wafer body ball valves (flangeless design) instead of flanged connection ball valves, based on a criterion given in ASME B16.34, in order to save space and cost. (The American Society of Mechanical Engineers 2004). The provided criteria are used to make sure that the wafer-type ball valves can be used safely in the process system, without any failure during the design life.

Figure 2: Cavitation Damage in plugs of the globe valves

Figure 3: Cavitation attack to a globe valve plug on sealing areas

Maintaining health, safety and environment (HSE) requirements, as well as failure analysis and prevention, improves the safety and reliability of the valves. Paper #4 demonstrates the industrial valve's technical requirements, in terms of seal ability during, and operability after, a fire (American petroleum Institute 2011). Paper #8 reviews the mitigation strategies used to reduce acoustic fatigue and the risk of operators’ hearing damage from pressure safety and control valves used in piping systems, including a case study from industry experience. Paper #9 concerns industrial valves’ safety integrity level (SIL) measurement, calculating the possibility of failure for the valves as well as SIL application on a 20” CL1500 gas export line ball valve (See Figure 4), to evaluate the possibility of its failure. Paper #16 provides key design considerations for the stem of valves, such as stem diameter calculation, anti-blow out feature, etc., to prevent stem failure. The stem of a valve is categorized as a pressure containing part, meaning that failure to function leads to a leakage of the fluid inside the valve to the environment. Paper #18 provides a literature review on factory acceptance testing for subsea valves and actuators. Subsea valves and actuators which are installed in deep water areas should be maintenance free during their design life, which could be 20 or 30 years, as an example. Thus, the valves require high reliability, which is achieved through different approaches such as very serious and accurate factory acceptance testing. Paper #18 provides additional testing for subsea valves and actuators, based on industrial experience, to improve their reliability.

Figure 4: 20" pipeline ball valve for gas export line

Design improvements and considerations for industrial valves have been reviewed and evaluated in six papers. Paper #6 addresses and recommends a new concept of design for check valves, according to minimum flow inside the pipe, to avoid chattering and operational problems. Paper #10 provides a numerical method to calculate the valve stem diameter and dimensions, to withstand operational loads from the valve operator without any failure. Paper #13 reviews a case study according to industrial experience on how to select a bypass valve for a control valve in the offshore industry, to achieve the required flow rate as a process parameter.

The performance of a valve is largely dependent on its actuator. Three factors are important for engineers to consider when selecting an actuator: frequency of operation, ease of access, and critical functions. Valve actuators should perform several functions, including moving the valve closure member to an appropriate position; holding the valve closure member in the desired position; providing enough force or torque to seat the closure member and meet the required shutdown leakage class; providing fully open or fully closed or failure mode as is; or providing a certain amount of closure member rotation at the right speed. In general, an actuator can be hydraulic, pneumatic or electrical (See Figure #5a & 5b). Papers #7 and #12 concern integrity between valves and actuators, as well as actuator selection for industrial valves, respectively. Paper #17 is a review of moving to electrical actuators rather than the hydraulic option for subsea valves, to improve efficiency, protect the environment and reduce operation time. An actuator is a machine or component installed on the top of an industrial valve to automatically move and control the valve.

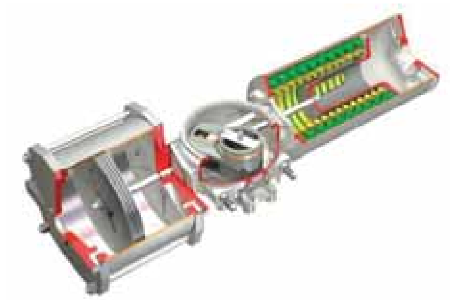

Figure 5: Pneumatic or hydraulic actuator and electrical actuator

Improving the reliability and safety of valves and actuators is frequently addressed in the published papers. Paper #1 proposes optimum material selection for different parts of the valves, to prevent valve failure to function due to different types of corrosion as well as loads. The paper not only focuses on the acceptable and optimum material choices. In addition, some materials which are not suitable for subsea valves, due to the high risk of corrosion, are briefly discussed in this paper. A finite element analysis has been applied to the body of a large-size valve on the oil export pipeline in Paper #2, to validate the design of the valve's shell or body (See Figure 6) (American Society of Mechanical Engineers 2012).

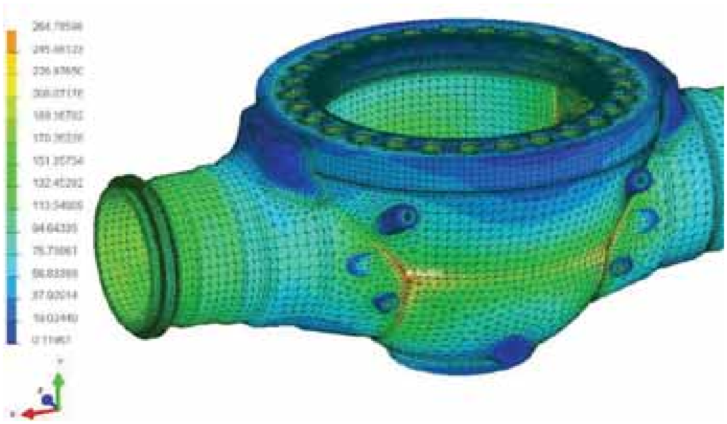

Figure 6: Finite element analysis on a body of a large-size ball valve

The valve shell or body failure to function would considerably jeopardize the safety and reliability of the valves. Failure of the valve body to provide sufficient mechanical strength against the pipeline loads lead to leakage to the environment, loss of asset and, in some cases, loss of human life. Paper #3 addresses cavitation prevention as a main type of corrosion in globe valves, which can lead to plant shutdown and loss of asset, as well as trigger safety and reliability issues and problems for the plants. Paper #5 provides a failure mode and effect analysis (FMEA) of the pipeline valves, to reduce the risk. Figure #7 illustrates the flow chart for implementation of the FMEA.

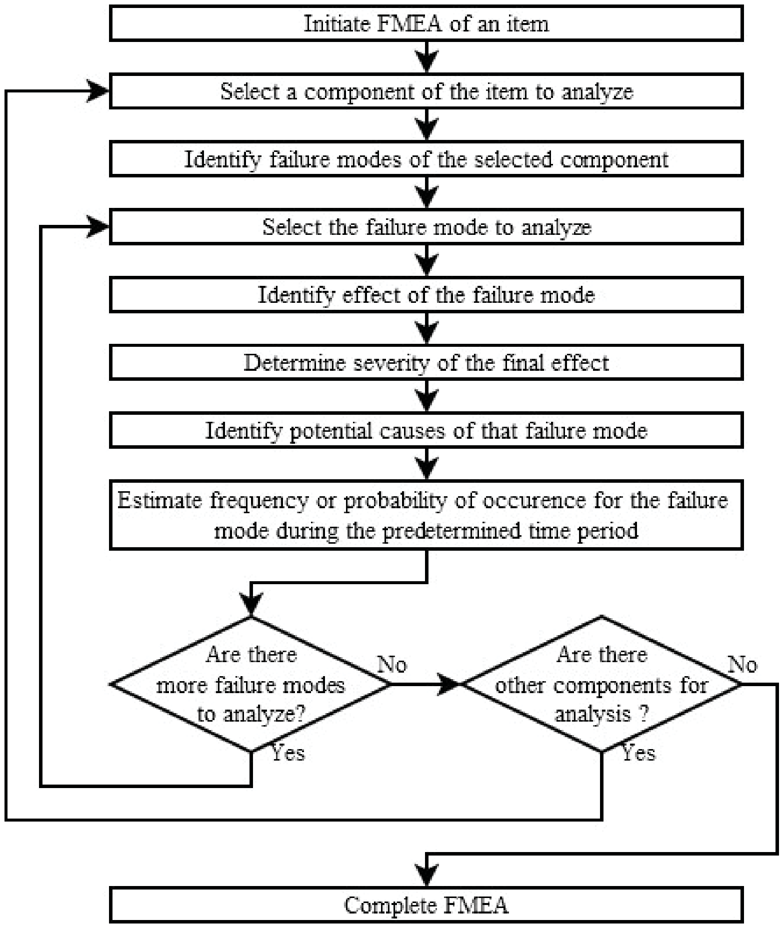

Figure 7: FMEA implementation

Potential risks associated with pipeline valves, as the most important valves on the platform, have been identified. All the risks have been quantified according to the probability and the impact of occurrence. The most severe and significant risks which lead to valve, as well as plant, failure, have been identified, and mitigation approaches are proposed, in order to considerably reduce the most critical risks associated with the most important valves. Paper #9 provides a methodology and a case study to calculate the safety integrity level

(SIL) in the actuated valve. SIL calculation is a numeric approach to evaluating the probability of the failure of actuated valves. Paper #16 focuses on some of the key design features of the valve stem. The stem is the part of the valve which transfers the loads from the valve operator to the valve internals. Failure of the stem to function adds operational costs, due to replacing the valve, as well as shutting down the plant. Thus, paying attention to accurate and proper stem design improves the safety and reliability of the valves and the plants. Paper #17 proposes all-electrical subsea systems and actuators, instead of using hydraulic-electrical, which is a hot topic in subsea systems. Shifting to an all-electrical subsea system and actuation improves the reliability of the subsea system through the removal of hydraulic systems. Hydraulic systems are not an environmentally friendly solution. Paper #18 provides detailed information about factory acceptance tests (FAT) on subsea valves and actuators. Subsea valves and actuators are installed under the water, where the requirements are for zero maintenance and leakage. One of the essential parameters which improves the safety and reliability of subsea valves and actuators is an accurate factory acceptance test. Some of the proposed tests are in accordance with international standards. Others are proposed according to the author's experience in the industry. Paper #19 focuses on online monitoring and ValveWatch as a topical issue related to valves in the offshore industry. Condition or online monitoring is related to series of sensors which are installed on the valves and actuators, in order to detect possible defects from the most important actuated valves (Jeeves 2016) (see Figure #8).

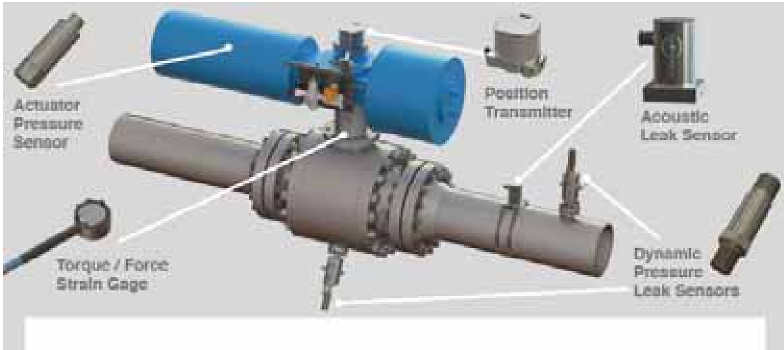

Figure 8: ValveWatch sensors

The important actuated valves are those with safety critical functioning. ValveWatch implementation has many advantages, such as the detection of many essential defects in the actuated valve at an early stage before the defect becomes critical. In addition, there is less need for traditional inspection and, therefore, for numbers of inspection personnel on the platform. All these improve the safety and reliability of the actuated valves, as well as the plant. This paper provides a numerical method to measure and validate the reliability improvement of the actuated valves due to the implementation of condition or online monitoring. Figure #9 summarizes all the effective parameters on improvements of valves' safety and reliability according to the published papers.

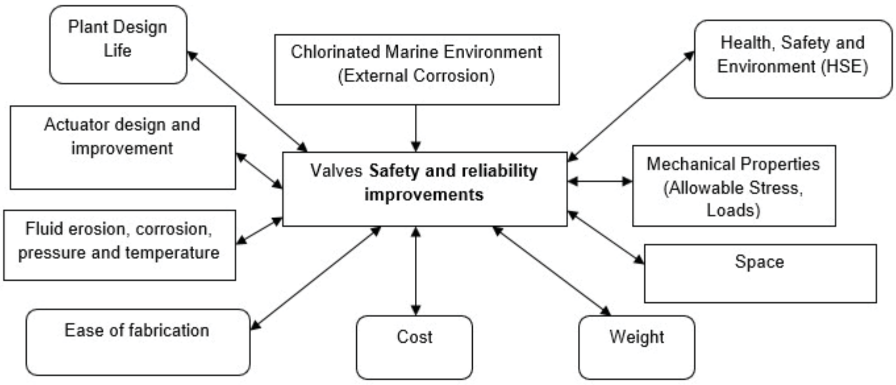

Figure 9: Key factors in valve design and selection for offshore

1.2 Aim of the research

Through the use of the different methods explained in the 19 attached published and approved papers, the main aim of the research is to improve the design and selection, safety and reliability of valves and actuators, by minimizing valve failure caused by material damage, corrosion, loads and stresses, due to piping or an actuator, etc. The proposed improvements developed in the thesis should satisfy the following targets for the industrial valves and, in some cases, actuators.

- Long design life and robustness;
- Withstanding marine environment, highly saline;
- Highly resistant against corrosion by fluids such as Carbon Dioxide (CO_2), Hydrogen Sulfide (H_2S), Chloride-containing fluid services;
- Suitable for required process conditions such as pressure and temperature;
- Resistant against erosion and cavitation where applicable;

- Lightweight;
- Compact design;
- Applicability to the available solutions on the market;
- Less fabrication, installation and general cost;
- Compatible with international and Norwegian standards and norms;
- HSE considerations like noise and Safety Integrity Level (SIL) and functionality of the valves in case of fire;
- Improving the safety and life cycle reliability.

What is unique in this research is that it combines and examines multiple parameters, from a practical point of view, for valve design, selection and reliability:

1. Conducting a literature review – including engineering standards and specifications like ASME, the American Petroleum Institute (API) and NORSOK, as well as looking at practical and essential cases in the Norwegian offshore industry, particularly in a very large project like Johan Sverdrup.
2. Reducing Cost of Expenditure (CAPEX) through the selection of more compact and lighter valves;
3. Proposing solutions for design improvement and the robustness of valves and actuators, leading to operational cost (OPEX) reduction and reliability improvement;
4. Establishing a guideline for material selection of subsea valves in the offshore sector of the oil and gas industry which is validated through real industry practices;
5. Developing a numerical model for corrosion allowance calculation on carbon steel valves;
6. Improving the safety and reliability of the subsea valves and actuators through more rigorous testing, based on industrial experience.

1.3 Motivation/Originality of the research / Main Research Questions

The main motivation to prepare this thesis is to reduce the cost of expenditure (CAPEX) and operation (OPEX) for valves and actuators in the offshore sector of the oil and gas industry and to improve safety and reliability. Maintenance of offshore facilities including actuators and valves is very costly and undesirable. The research aims to present new and practical information regarding the design and selection of piping and valves in the offshore industry. In introducing and analyzing series of design improvements in different practical cases, the research takes a unique approach. The originality of the research is based on capturing and applying multi factors mentioned in Section 1.2 ***Aim of the research*** for valve, piping and actuator design and selection. The main research questions are listed under the header, “Research contribution to develop new knowledge” in Figure #10.

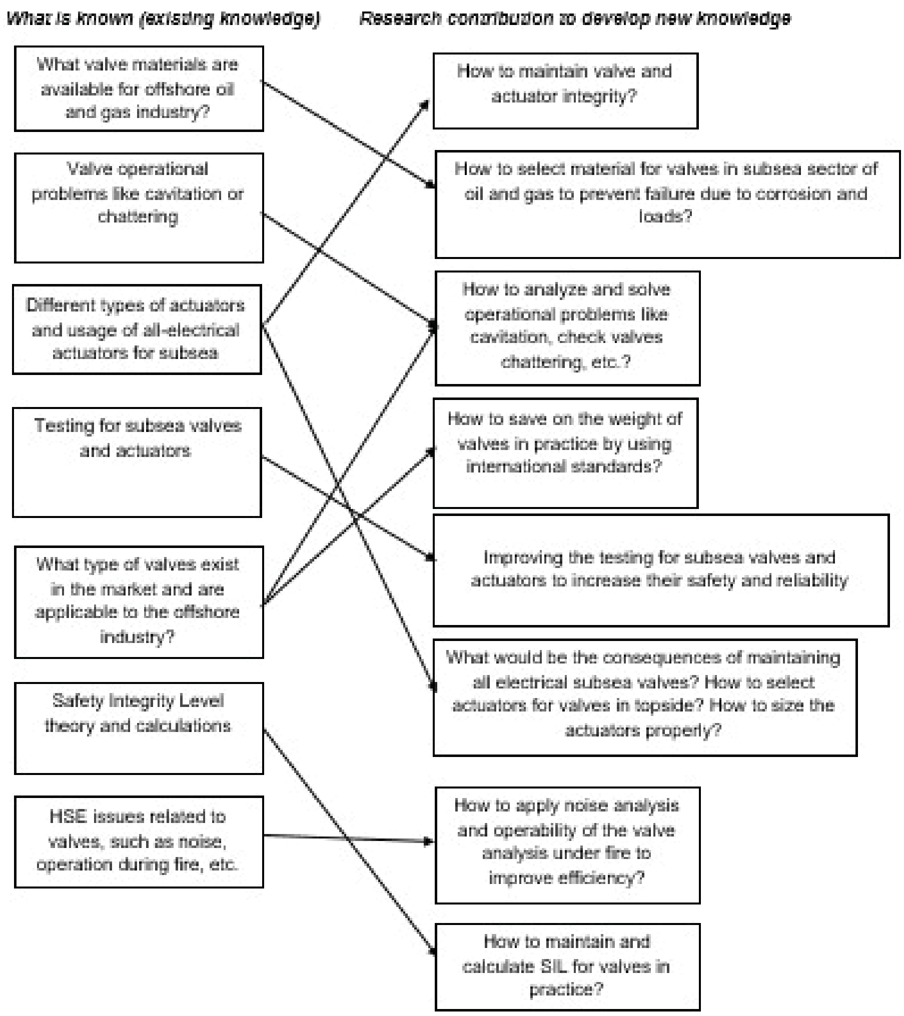

Figure 10: Research contributions to develop new knowledge

2. Methodology (Developing research objectives)

Each objective given in Section 1.2 of this thesis will be split into smaller tasks in order for the project objectives to evolve. The **first objective** is **safety and reliability improvement, directly or through a design improvement which consequently reduces the operation cost (CAPEX).** The tasks to develop this objective are:

1. Optimizing material selection for subsea valves, to mitigate corrosion risk (Paper #1)

2. Addressing cavitation as a main operational problem for globe valves and providing solutions to mitigate this risk (Paper #3)

3. Evaluating the valves' sealing and operability in case of fire and after fire, through thermal analysis, to maintain HSE (Paper #4)

4. Using an FMEA to evaluate the risks associated with pipeline valves and quantifying them, as well as proposing mitigation approaches to reduce the risks for these valves during operation (Paper #5)

5. Designing the check valves based on minimum flow, to avoid operational problems like chattering of the check valves (Paper #6)

6. Improving the integrity of the valve and actuator (automatic operator) against different loads such as blast, through a case study, and minimizing the chance of breakage between valves and actuators (Paper #7)

7. Analyzing noise and fatigue in the valves, to prevent fatigue failure of the valves and hearing problems due to noise for the personnel working on site (Paper #8)

8. Applying a Safety Integrity Level (SIL) for emergency shutdown valves with a high degree of safety expectation, to evaluate and reduce the possibility of failure for these valves (Paper #9)

9. Developing a practical model to make sure that the stem of the valves, as a pressure-containing part which transfers loads from the valve operator to the valve internals, is robust enough (Paper #10)

10. Improving valve selection for bypass valves of the control valves, to optimize and improve the process efficiency (Paper #13)

11. Developing a model to calculate the corrosion allowance for carbon steel piping and valves, to mitigate sweet-type corrosion risk (Paper #15) (NORSOK 2005).

12. Shifting to all-electrical actuators in subsea, to improve HSE, compared to the selection and use of hydraulic actuators (Paper #17)

13. Reviewing factory acceptance tests for the subsea valves and actuators. Testing the subsea valves and actuators has a considerable impact on their reliability. In addition to those introduced in the international standards, the paper proposes some new types of test, based on industry experience, to reduce the chance of failure for subsea valves and actuators (Paper #18)

14. Strong proposal to use ValveWatch or online condition monitoring for safety critical valves, for better detection of defects and to increase reliability (Paper #19)

The **second objective** is to review **the specifications and international and Norwegian standards, as well as practical cases in the Norwegian offshore industry.** The tasks to develop and cover the above-mentioned objective are:

1. Reviewing Norwegian standards for corrosion study and piping and valve material selection, such as NORSOK M-001 "Material Selection" (NORSOK 2014), NORSOK M-506 "CO_2 Corrosion Model" (NORSOK 2005)., and TR2000 "Equinor Piping and Valve Material Specification".

2. Reviewing International standards and codes for valves, such as ASME B16.34 Valve Standard, ASME Section VIII Boiler and Pressure Vessel Code, ASME B16.10 Valve End to End Dimensions, API 609 Butterfly Valves Standard, API 594 Check Valves Standard, etc. (American Society of Mechanical Engineers 2001 & 2004; American Petroleum Institute 2004).

3. Collecting different cases in three Norwegian offshore industry projects while I was working for AkerSolutions in Fornebu as a specialist piping and valve engineer. Most of the cases relate to the Johan Sverdrup project, including four platforms and one of the largest oilfields and projects in the history of Norway. The Johan Sverdrup oil field is located in the North Sea, about 140 kilometers (87 mi) west of Stavanger, Norway. The field lies in two different production licenses and consists of two different discoveries, called Avaldsnes (where Lundin Petroleum is the operator) and Aldous Major South (where Equinor is the operator). The second project is the Edvard Grieg field, located in the Utsira High area in the central North Sea. The Utsira High area is Lundin Norway's main focus area, with the majority of Lundin Norway's 2P reserves and contingent resources situated in this area. The third one is the Johan Castberg (formerly Skrugard) field development project, comprising two oil fields, namely Johan Castberg and Havis, located in production license

PL 532, about 100km north of the Snøhvit field in the Barents Sea. The two oil fields are located at water depths of about 360m to 390m with current recoverable reserves estimated at being 400 to 600 million barrels of oil. The production capacity of the fields is estimated at 200,000 barrels of oil equivalent each day.

4. Reviewing different piping, material and valve handbooks, such as *Valve Selection Handbook* by Peter Smith, published by Elsevier, *Handbook of Valves and Actuators* by Brian Nesbitt, *Norwegian Valve Handbook*, as well as *Valve Handbook*, published by MacGraw Hill.
   (Smith & Zappe 2004; Skousen 2004; Nesbitt 2007)

The **third objective** is **to reduce the cost of expenditure (CAPEX), by selecting and designing lighter and more compact piping and valves, as well as an optimized fabrication method.** As previously mentioned, using lighter piping and valves is more important offshore than onshore, since greater weight means heavier loads on the platforms and jackets, and it is more difficult and challenging to transport heavier platform topside modules, including piping, structure and equipment. Additionally, due to the lack of available space on topside platforms and ships, it is important to apply a compact design to industrial valves and piping. The following tasks have been implemented to achieve the third objective:

1. Introducing and applying a state-of-the-art method for design optimization and weight-saving of pipeline valves in the offshore industry, by using the calculation method given in ASME Sec. VIII Div.02 (American Society of Mechanical Engineers 2012). (Paper #2)

2. Developing a numeric model to evaluate the use of wafer-type ball valves as a lighter, more compact and less costly choice, compared to the flanged end type of connection (Paper #14)

3. Using all-electrical subsea valve actuation, which leads to subsea and topside weight-saving (Paper #17)

The **fourth objective** is to provide **a material selection guideline for subsea valves.** The following tasks will be established to achieve this objective:

1. Defining the type of subsea valves in the manifolds, as well as proposing different options for materials for each part of the valve (Paper #1)
2. Providing optimum material selection for each part of the valve, including advantages and disadvantages (Paper #1)

The **5th objective** is to **develop a numeric method to calculate the corrosion allowance for carbon steel piping and valves.** The following tasks will be established to achieve this objective:

1. Reviewing different corrosion texts and standards

Developing a method for calculating corrosion allowance, based on process parameters for carbon steel piping and valves (Paper #15)

3. Appended papers

3.1 Introduction

There are 19 main papers that have been covered in the research proposal as well as literature review listed below:

1. ***Optimized material selection for subsea valves to prevent failure and improve reliability*** (Publisher: Journal of Life Cycle Reliability and Safety Engineering, Springer, 2020)
2. ***Pipeline valve technology, material selection, welding and stress analysis (A case study of a 30inch Class 1500 pipeline ball valve)*** (Publisher: American Society of Mechanical Engineers (ASME), Journal of Pressure Vessel Technology, 2018)
3. ***Selecting a butterfly valve instead of globe valve for fluid control in a utility service in the offshore industry (Based on industrial experience)*** (Publisher: American Journal of Mechanical Engineering, 2018)
4. ***Valve operability during a fire*** (Publisher: American Society of Mechanical Engineers (ASME), Journal of Offshore Mechanics and Arctic Engineering, 2019)
5. ***Failure mode and effect analysis (FMEA) of pipeline ball valves in the offshore industry*** (Publisher: Journal of Failure Analysis and Prevention, Springer, 2020)
6. ***Comparing dual plate and swing check valves and the importance of minimum flow for dual plate check valves*** (Publisher: American Journal of Industrial Engineering, 2018)
7. ***Valves and actuators integrity and blast load calculations*** (Publisher: Springer Nature Applied Science, 2019)
8. ***Noise and acoustic fatigue analysis in valves (Case study of noise analysis and reduction for a 12" x 10" pressure safety valve)*** (Publisher: Journal of Failure Analysis and Prevention, Springer 2019)
9. ***Safety Integrity Level (SIL) in valves*** (Publisher: Journal of Failure Analysis and Prevention, Springer 2019)
10. ***The importance of maximum allowable stem torque in valves*** (Publisher: Springer Nature Applied Science, 2019)
11. ***A review on subsea process and valve technology*** (Publisher: Journal of Marine Systems & Ocean Technology, Springer Nature Applied Science, 2019)

12. ***Actuator selection and sizing for valves*** (Publisher: Springer Nature Applied Science, 2019)
13. ***Challenges associated with the bypass valves of control valves in a seawater service*** (Accepted by: Springer, Journal of Marine Science and Application, 2020)
14. ***Wafer design valve verification based on ASME B16.34*** (Publisher: Springer Nature Applied Science, 2019)
15. ***Requirement and calculation of corrosion allowance for piping and valves in the oil and gas industry*** (Publisher: Journal of Bio- and Tribo-Corrosion, Springer, 2020)
16. ***Optimized valve stem design in oil and gas industry to minimize major failures*** (Publisher: Journal of Failure Analysis and Prevention, Springer, 2020)
17. ***All electrical subsea control systems and the effects on subsea manifold valves*** (Publisher: Journal of Marine Science and Application, Springer 2020)
18. ***Subsea valves and actuators: A review of factory acceptance testing (FAT) and recommended improvements to achieve higher reliability*** (Publisher: Journal of Life Cycle Reliability and Safety Engineering, Springer, 2020)
19. ***Development of a numeric method to validate the reliability improvement of safety critical valves during operation through online monitoring implementation*** (Publisher: Journal of Sensing and Imaging, Springer, 2020)

Figure #11 illustrates how the papers are linked together. More information about the logic of linking the papers is given in Section 5.

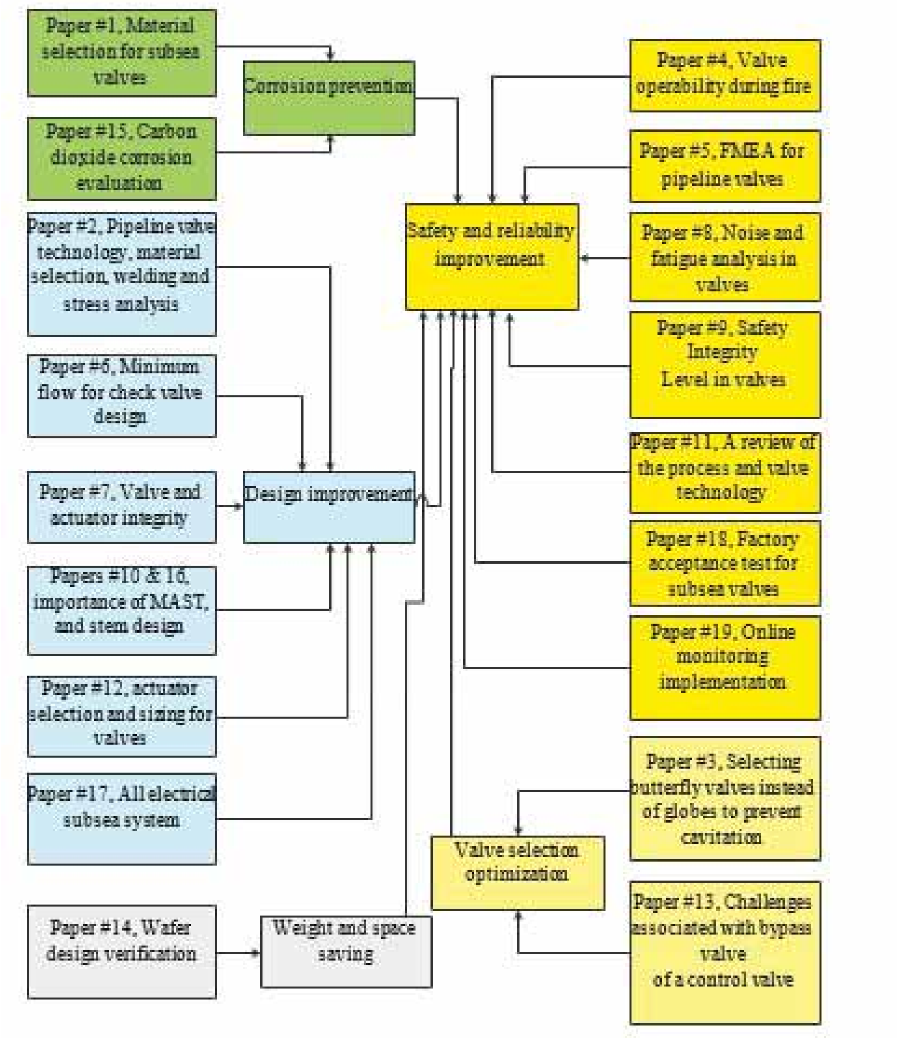

Figure 11: Published papers' link

3.2 Review of appended papers

Paper #1) Optimized material selection for subsea valves to prevent failure and improve reliability

Objective

To select the optimized materials for subsea valves, to prevent corrosion, improve the design, prevent environmental pollution and, finally, improve safety and reliability

Discussion presented in paper

Subsea valves which are sometimes installed in ultra-deep areas (one to three kilometers) in the sea or ocean should be free of leakage and failure- and maintenance-free. The paper focuses on different types of subsea valves inside a subsea manifold. The subsea manifold is a unit made of steel structures, piping and valves, which collects the fluid from different wellheads and combines it into one or more headers. Use of the manifold is important in subsea, in order to minimize subsea piping. Three types of valves which are used in the manifolds are ball valves, through conduit gate valves and axial check valves. Through conduit gate valves are used for the manifold branches, while ball valves are used for the headers. Axial valves are used on chemical injection lines, such as methanol and mono-ethylene glycol, which are injected into the gas to prevent hydrate formation.

The main focus of the paper is on the selection of material for the subsea valves. Material selection is an important part of valve design. Subsea valves are exposed to both internal and external corrosion, as well as erosion. Untreated oil and gas coming out from the reservoir and the well contains many corrosive compounds, such as hydrogen sulfide and carbon dioxide. In addition, a large amount of sand occurs in the produced hydrocarbon. The valve is in contact with the seawater externally and sometimes internally, which increases the corrosion rate. In addition, subsea valves should withstand high loads, due to the pressure inside the pipe and connected piping. Additionally, the seawater head pressure on the valve installed at deep depths of water, such as two kilometers, provides a high level of external pressure.

Conclusion

Different choices of materials, such as low alloy steel, duplex, Inconel 625, etc., are introduced and considered for different parts of the valves, such as body, bonnet, stem, seats, closure member, bolting, pup piece, etc. The paper concludes on the advantages and disadvantages of each choice of material. This research helps engineers in the industry to select the optimum materials for the valves, to prevent valve failure due to material corrosion and erosion, as well as applied loads.

Paper #2) Pipeline valve technology, material selection, welding and stress analysis (A case study of a 30inch Class 1500 pipeline ball valve)

Objectives

Introduction to and review of pipeline valves, as the most important valves on the platform to be used in the oil or gas export pipeline.

Discussion presented in paper

Pipeline valves are the largest, heaviest, and most important valves on an offshore platform, with a long delivery time. A pipeline valve is either a ball-type or through conduit gate-type with a top entry design. The top entry design provides advantages, such as a lower risk of leakage, greater mechanical strength against pipeline loads, and ease of maintenance (online maintenance), compared to the side entry design. A 30-inch pipeline ball valve, in class 1500 and carbon steel body material, was chosen for stress analysis in this paper. The valve was connected to the pipeline through pup pieces from both sides. The pup pieces were connected to the body of the valve through transition pieces. The large 30-inch valve has an emergency shutdown safety function and is equipped with a hydraulic actuator. The design of the valve is based on the American Petroleum Institute (API) 6D Specification for Pipeline and Piping Valves (American Petroleum Institute 2014). The proposed formula of wall thickness calculation in this paper is based on the American Society of Mechanical Engineers (ASME) Section VIII, Division 2, Boiler and Pressure Vessel Code (BPVC), instead of the ASME B16.34 standard (American Society of Mechanical Engineers 2004 &2012). (The wall thickness values given in the ASME B16.34 standard for “Valves Flanged, Threaded and Welding End” are very conservative and thick, making pipeline valves heavier and more expensive (American Society of Mechanical Engineers 2004). Noticeably, ASME B16.34 requires an even greater thickness, due to assembly loads, actuation (opening and closing) loads, etc. (American Society of Mechanical Engineers 2004). These valves should withstand loads from pipeline systems such as axial, torsion, and bending moments. ASME B16.34 does not specify the body wall thickness of the pipeline valves under the pipeline loads and moments (American Society of Mechanical Engineers 2004). This paper aims to create a model to prove that the 30-inch Class1500 pipeline valve will withstand the loads and moments with the thickness of the valve calculated using ASME Section VIII, Division 2 methods (American Society of Mechanical Engineers 2012).

Conclusions

There are two main findings in this paper; the first is how to weld the valves located on the pipeline which are in carbon steel to a pipeline in duplex. (Challenge in welding two different materials). The pipeline material is selected in duplex, instead of carbon steel, in order to reduce the weight and thickness of the pipeline. Duplex has greater mechanical strength than carbon steel, so selecting duplex instead of carbon steel for piping can reduce its thickness and weight. However, selecting duplex for a pipeline valve does not save the weight of the valve and makes the valve very expensive. Welding carbon steel to 22Cr duplex material in thicknesses greater than 19 mm is challenging. The reason is that carbon steel material requires post weld heat treatment after welding to remove the residual stress inside the material, as per the ASME B31.3 “Process piping” recommendation (American Society of Mechanical Engineers 2012). However, applying post weld heat treatment on 22Cr duplex can provide an intermetallic sigma phase in duplex. Therefore, a method based on applying Inconel 625 buttering on carbon steel and applying post weld heat treatment, and then welding the buttered carbon steel to duplex with Inconel 625 filler, was used. The second main finding is that calculating the wall thickness of the valve, as per ASME Section VIII Div.02 instead of ASME B16.34, considerably reduces the weight of the valve. The second finding leads to design optimization of these important valves. (American Society of Mechanical Engineers 2004 &2012) A finite element analysis has been performed in this paper to validate the optimum design proposed as per ASME Section VIII (American Society of Mechanical Engineers 2012).

Paper #3) Selecting a butterfly valve instead of globe valve for fluid control in a utility service in the offshore industry (Based on industrial experience)

Objectives

Mitigating the risk of cavitation as the main operation problem for globe valves, through design improvement, hard facing, as well as selecting a butterfly valve instead of a globe valve. Cavitation is a type of corrosion-erosion which reduces safety and reliability, through damage to the valve internals, shutting down the plant, extra maintenance implementation, etc.

Discussion presented in paper

Straight pattern globe valves are widely used in the oil and gas industry to regulate and control the flow of fluids. During operation, these valves are exposed to problems such as cavitation. Cavitation occurs when the pressure in a liquid suddenly drops, leaving behind a bubble of gas. There are some strategies that can be used to mitigate the risk of cavitation, such as designing the valves as per API 623 standard (American Petroleum Institute 2013), selecting a different valve type, such as Y-Type or axial valves, or hard facing the valve internals. These solutions increase the cost of valve selection and are more suitable for valves in process services, such as valves containing hydrocarbon. The main question this research seeks to answer is whether a butterfly valve (e.g., wafer-type) is a good replacement for a straight pattern globe valve in utility services such as water. It is noticeable that wafer-type butterfly valves are much cheaper than globe valves, especially when it comes to exotic materials. Twelve control valves in water services in titanium and duplex in an offshore unit were selected for research. The manual valves on the bypass of the control valves were evaluated for globe or butterfly valve selection. The data analysis included two methods of cavitation analysis and pressure drop analysis. The risk of cavitation is almost the same for both butterfly and globe valves. The analysis shows that butterfly valves are slightly more prone to cavitation risk. When it comes to pressure drop calculation analysis, none of the globe valves was suitable. On the other hand, six butterfly valves were suitable for the fluid control after pressure drop and cavitation analysis. In conclusion, butterfly valves are recommended for fluid control in utility services such as water.

Cavitation, which creates irregularities and pitting inside the valve and is known as one of the main operational problems for straight pattern globe valves, has been addressed by many operating companies around the world, such as Equinor and Fluor. Therefore, different solutions to prevent cavitation have been addressed and introduced in this paper, such as using axial valves and Y-type globe valves.

Cavitation causes valve failure (loss of asset) and consequently leads to the shutdown of the connected process or utility line to the valve.

In two recent Norwegian projects, Johan Sverdrup and Johan Castberg, Equinor proposed selecting wafer-type butterfly valves instead of globe valves in water services, to prevent cavitation. Changing the globe valves to butterfly valves received some restrictions from the process department in the EPC (Engineering, Procurement and Construction) contractor company. The process department were opposed to using butterfly valves, as their idea was that butterfly valves are also subject to cavitation. Thus, a cavity analysis has been performed for both candidate valves to justify the use of butterfly valves instead of glove valves to prevent cavitation.

Conclusion

The key findings of this paper provide solutions to solve cavitation, to improve the safety and reliability of the globe valves. In addition, a model or formula based on the existing literature is given in the paper, to evaluate the cavitation. The paper in general proposes butterfly valves instead of globe valves to prevent cavitation, as a new finding.

Paper #4) Valve operability during a fire

Objectives

Validation of the valve's operability during a fire.

Discussion presented in paper

Fire and explosion are a major cause of concern for refinery, gas processing, petrochemical, and gas installations. The safest way to deal with a fire is to prevent it. However, fire prevention strategies are not always successful, and fires can occur. Therefore, valves should be designed and tested to be fire-safe. This paper reviews valve design features that can help prevent fires, including secondary sealing between the ball and body, in the case of losing a soft seat; a graphite fire-safe ring design for stem and seat sealing; antistatic devices; and antistatic tests, to ensure that the valve is fire-safe. In addition to design considerations, a fire-safe design should be validated through tests defined in standards such as API 607 and API RP 6FA (American Petroleum Institute 2011 &2016). The API RP 6FA (American Petroleum Institute 2011). tests reviewed in this paper include seven tests that check the operability of the valve from closed to open position. A case study was carried out to prove the operability of a fail close 38” pipeline ball valve on an oil export pipeline, from the open to closed position, during the first 20sin the case of fire. Thermal analysis of the body of the valve proved that there was no thermal expansion inside the valve after 150s of fire. Additionally, the maximum radial displacement on the valve body after 150s of fire was 0.34mm, which is negligible. Thus, valve thermal expansion did not disturb the operation of the valve after 20s.

Conclusion

Valves should provide functionality and sealability during and after the fire to some extent, as per the above-mentioned ISO (International Organization for Standardization) and API (American Petroleum Institute) standards. The sealability and functionality of valves during a fire is very important, to prevent loss of product and environmental pollution. In addition, it is important to operate the valve from open to closed position in case of fire, as per standard requirements. The paper provides a thermal analysis, to ensure that the expansions in the valve body and internals would not prevent the valve’s operation during and after the fire. The key finding is to provide a thermal analysis to ensure the valve’s operability during and after a fire.

Paper #5) Failure mode and effect analysis of pipeline ball valves in the offshore industry

Objective

FMEA implementation for the pipeline valves, to identify the major risks associated with these types of valves, due to poor design, test, etc., and mitigate or prevent the risks.

Discussion presented in paper

This article provides a practical method for applying failure mode and effect analysis (FMEA) of oil export pipeline ball valves. These valves have been selected for analysis because they are the largest, heaviest, and most important valves on topside platforms in the offshore sector of the oil and gas industry. FMEA is a systematic approach for the evaluation and identification of potential failures associated with the design and operation of pipeline valves. A literature review is included, to provide more detailed information about the operation, components, and failure modes of pipeline ball valves. Five failure possibilities associated with pipeline ball valves were identified, including leakage from the body and seat of a valve during operation; lack of a proper factory acceptance test; valve body damage due to pipeline loads because of insufficient thickness; missing the finite element analysis of the body of the valves; and seat damage, as a result of wax ingress. The severity and possibility of occurrence were defined and assigned to each possible failure. A risk priority number was calculated for each failure mode, on a scale of 1–100. Two risk items were recognized as critical, with score values between 50 and 60. The outcome of FMEA shows that seats of pipeline valves are the most exposed components at risk of failure. The most critical identified failure related to the seats is accumulation of wax in the seat area. The proposed solution is to apply flushing ports and double-isolate them with modular valves, to minimize the risk of leakage to the environment. The second critical failure is related to damage to the valve body due to pipeline loads. Valve wall thickness calculations, in accordance with ASME Sec. VII DIV.02., and stress analysis of the valve body, based on different loads, are proposed, to minimize the risk of a second failure (American Society of Mechanical Engineers 2012).

Pipeline valves are the most important valves in the topside sector of the offshore industry. Topside sector refers to the facilities on a platform or a ship. These valves, which have been reviewed in more detail in Paper #2, are typically installed on the oil or gas export pipeline to transmit the produced hydrocarbon to its destination. Any failure to these valves can significantly jeopardize the safety and reliability of the plant. Firstly, these valves are very expensive assets. Secondly, their failure means production stoppage, which is a loss of money. Thirdly, failure of these valves involves a high maintenance cost. Thus, it is important to identify the failure risks associated with these valves and mitigate them. This paper provides a risk assessment of these valves, from identifying the main risks which can lead to their failure to quantifying the associated risks. The first important risk with the highest score for these valves could be accumulation of wax in the seats, which can prevent the sealability of the valve. Providing a valve wash is proposed, to mitigate this risk. The second possible risk of failure of these valves could be damage to the valve body, due to the loads on the valves. Therefore, a finite element analysis to validate the design of the valve, especially body and bonnet as pressure-containing parts, is strongly recommended in this paper. Paper #2 provides a methodology and case study on how to apply Finite element analysis (FEA) to prevent leakage from the valve. Thus, this paper is highly connected to Paper #2, to improve the design as well as safety and reliability. A method for applying FMEA as a part of risk analysis is an important finding and part of this paper.

Conclusion

This research involves a detailed investigation into the pipeline ball valves used in export lines. The FMEA method was used to analyze five failure modes relevant to four pipeline valve components: seat, body, ball, and actuator. The analysis shows that the highest risk score is associated with the seats of the valves, with an RPN (Risk Priority Number) of 95. The main seat failure risk is due to ingress of wax (hard oil) to the seat arrangement, with a score value of 56 out of 100. This problem can be addressed and mitigated by using flushing ports on the seat arrangement. Modular or double block and bleed valves are proposed for double-isolation purpose, since flushing ports introduce a potential additional leakage path on the valve body. The second highest failure mode score is related to damage of the valve body due to pipeline loads, with a score of 54 out of 100. The main reason for this failure is related to an insufficient valve thickness calculation, as well as a missing FEA on the valve body. An optimum wall thickness calculation, based on ASME Sec. VIII Div. 02, is proposed, to save the weight and thickness, compared to ASME B16.34 for pipeline valves (American Society of Mechanical Engineers 2004 & 2012).
. Different loads, such as axial, torsion, and bending, during design and maintenance, and accidental loads, should be identified and included in the valve 3D model for FEA.

Paper #6) Comparing dual plate and swing check valves and the importance of minimum flow for dual plate check valves

Objective

Addressing and mitigating chattering, as one of the main operational problems of the check valve, and focusing on designing the check valves according to the minimum flow.

Discussion presented in paper

Check valves are automatic valves that open with forward flow and close against reverse flow. The main function of a check valve is to protect mechanical equipment in a piping system by preventing fluid reversal. A swing check valve is an economical type of check valve, but it has a high slamming effect. Dual plate check valves are more popular than swing check valves in the Norwegian offshore industry because they have a low slamming effect. Additionally, the total cost of a dual plate check valve—initial cost, maintenance cost, and energy cost—is less than that of a swing check valve. In fact, a swing check valve involves greater pressure drop and energy consumption in the pumping system. However, the minimum flow capacity may not produce enough pressure during the use of dual plate check valves, resulting in two operational problems. The valve loses more pressure when it is not in a fully open position, and, in addition to a rise in energy consumption, insufficient flow velocity can cause wear to the valve. A case study of minimum flow capacity and velocity calculation for fully opening a 22Cr duplex dual plate check valve in ASME pressure class 300 is discussed in this paper. The minimum flow in the example is lower than the minimum critical flow required to fully open the valve. Thus, to avoid operational problems, it is recommended that the valve is not operated with minimum flow. The other recommendation is to avoid installing the valve on the vertical line. Reducing the size of the valve and spring torque behind the disk are two other solutions to mitigate operational risks due to a minimum flow condition.

Conclusion

This paper addresses chattering as a main operational problem for the check valves. Chattering means constant closing and opening of the valve during the operation, which could lead to flow fluctuation and probably reduce the amount of production. Two key proposals in this paper to prevent chattering are:

- Making sure that the valve is in fully open position while the minimum flow rate is passing through the valve;
- If the minimum flow cannot fully open the valve, then some modifications inside the valve may be required, such as reducing the size of the valve or the spring torque behind the valve, to reduce the weight of the valve or the force required to open the valve.

Paper #7) Valves and actuators integrity and blast load calculations

Objective

Prevention and mitigation of the disconnection of the actuator from the valve, to prevent an unreliable and unsafe condition for the valve. A valve without an actuator cannot be operated.

Discussion presented in paper

Valve automation is an important topic in the oil and gas industry. Automation of valves leads to fewer personnel on platforms or ships for the operation of valves. Actuators are important parts of valve automation which are installed on top of the valves. This paper focuses on the mechanical integrity between the valves and their connected actuators. The connection between the valve and actuator is achieved through installation of the coupling. The coupling and connection of the valves and actuators should be strong enough to prevent disconnection of the actuator from the valve. Valves without actuators cannot be operated, opened and closed. Let us suppose that a valve has an emergency shutdown function, which should be closed to prevent a failure of the plant in the case of an emergency. If the actuator is disconnected from this emergency shutdown valve, the valve cannot be closed in case of emergency, and the safety and reliability of the plant would be in danger. Thus, the connection between the actuator and the valve should be strong enough to withstand the loads from the actuators, wind, snow and blast.

Conclusion

The paper reviews different parameters which affect the integrity between the valves and actuators, such as material of coupling, frequency of actuator operation and cycling, direction of valve and actuator installation on the vertical or horizontal line, fabrication of the coupling located between the valve and actuator in terms of number of pieces, etc. In offshore projects, it is the responsibility of the valve purchaser to inform the manufacturer of the valve and actuator about the applied drag force to the actuated valve generated because of the blast load. The valve and actuator manufacturer should ensure that the connection between the valve and the actuator is strong enough to withstand the blast load. The paper provides a method to ensure that the connection between the valve and the actuator is strong enough to withstand the blast load. The reason for the concentration on the blast load in this paper is that it could be one of the strongest forces leading to the removal of the actuator from the top of the valve.

Paper #8) Noise and acoustic fatigue analysis in valves (Case study of noise analysis and reduction for a 12" x 10" pressure safety valve)

Objective

Noise measurement and prevention in safety valves, to protect the valve from fatigue stress and prevent hearing damage to the personnel on site.

Discussion presented in paper

Safety and instrument engineers regularly analyze the noise in different types of valves to reduce its effect in sectors of the oil and gas industry such as offshore, refineries, and petrochemical plants. This paper reviews the mitigation strategies used to reduce acoustic fatigue and the risk of hearing damage from pressure safety valves and control valves used in piping systems. These two types of valves can generate high-frequency acoustical energy downstream of the valves. Different strategies are used to mitigate noise levels, such as installation of low-noise valves, process optimization to reduce the flow or delta pressure across valves, changing the valve design, acoustic piping installation, and increasing piping thickness.

This paper discusses a case study of a noise calculation for a pressure safety valve (PSV) at 1 m and 30 meters from the PSV discharge. The calculated noise level based on API 521, the standard for PSVs, has been compared with the maximum allowable noise limit from PSVs (American petroleum Institute 2014). The maximum allowable noise limit is calculated based on the NORSOK L-002 standard developed by Standards Norway (NORSOK 2009). If the calculated noise level based on API 521 exceeds the allowable or acceptable noise limit based on NORSOK standards, the piping wall thickness should be increased, to mitigate the risk of acoustic fatigue. The 1200 6MO piping wall thickness outlet line of a PSV is calculated based on the ASME B31.3 process piping code (American Society of Mechanical Engineers 2012). The outlet pipe from a PSV is in 6MO UNS 31254 material, which is expensive. Fortunately, there is no need to increase the piping wall thickness if the calculated noise based on the API 521 standard is within the accepted noise limit in the NORSOK standard.

Reducing the noise level is important, since it can lead to failure of the valves, due to fatigue, and cause hearing problems for personnel working on site. The fatigue damage to both pressure safety valves and control valves, as well as piping connected to these valves, has negative consequences. Pressure safety valves release the extra pressure inside the piping or pressure vessels. Thus, the malfunction of pressure safety valves could lead to overpressure of the piping or pressure vessels and cause explosion of the plant. Fatigue damage to the control valves causes loss of production and asset. Thus, the failure of both types of valves jeopardizes the safety and reliability of offshore plants and units.

Conclusion

The key findings in the paper are, firstly, the introduction of different strategies to prevent the high noise levels mentioned above. The second key finding, based on existing standards, is to calculate the noise level generated by a pressure safety valve as per API 521 and check the acceptance rate of this level of noise with the NORSOK L-002 standard (American petroleum Institute 2014 & NORSOK 2009).

Paper #9) Safety Integrity Level (SIL) in valves

Objective

Addressing and measuring SIL for safety critical valves, to ensure the safety and reliability of these valves during operation.

Discussion presented in paper

The Safety Integrity Level (SIL) is a part of international standards, such as IEC 61508, that provides suppliers and end users with a common framework to design products and systems for safety-related applications. SIL provides a scientific and numeric approach to specifying and designing safety systems, enabling risk of failure to be quantified. The probability of failure on demand and the probability of dangerous failure per hour on safety functions for each SIL level are given in the IEC (The International Electrotechnical Commission) standard. This paper reviews a 2000 pneumatic actuated ball valve in low temperature carbon steel material ASTM A352 LCC and pressure class 1500 equal to 258.6 barg at ambient temperature (38°C), which has an emergency shutdown (ESD) function. The ball valve is installed on a gas export pipeline that transfers the gas from an offshore platform to onshore. The ball valve is usually open, but it will be closed in the case of failure in the pipeline, to stop production and allow maintenance on the pipeline. The system includes an integrated valve, actuator, and control panel as a single unit that corresponds to one-channel (1oo1) architecture in international standards such as IEC 61508. Associated failure possibilities, such as dangerous detected and undetected as well as safe failure types, were assigned to the valve, actuator, and control panel, separately. Calculating the safe failure fraction for the whole system, as well as each single component separately, proved that the safety level of the system is categorized as SIL 2, which is in accordance with client demand.

Conclusion

The importance of SIL (Safety Integrity Level) is to calculate and evaluate the probability of dangerous failures for some special valves in the offshore sector of the oil and gas industry. SIL evaluation is required for safety critical valves. Safety critical valves are those which have an emergency shutdown or process shut-down function. These two groups of valves should have high safety and reliability, since their failure to function can destroy the plant. As an example, emergency shutdown valves should be closed very quickly in the case of a hazardous rise or fall in critical process parameters such as temperature, pressure or flow. If any or a combination of critical process parameters are not within the normal range, this abnormal condition should be stopped. Abnormal process conditions could jeopardize the safety and reliability of the plants; for example, a high-value pressure in a line could damage the line and cause explosion, loss of asset, loss of production and damage to human life. The case study in the paper can be used as a model for calculating the SIL for safety critical valves. Typically, SIL 3, with very low probability of failure between 0.0001 to 0.001, is expected, or SIL 2, with low probability of failure between 0.001 to 0.01, is expected and should be applied to safety critical valves. This means that the probability of safe working on safety critical valves should be more than 99.9%.

Paper #10) The importance of maximum allowable stem torque in valves

Objective

Designing of the valve stem, as an essential pressure-containing part, to withstand the loads from the operators without failure.

Discussion presented in paper

The maximum allowable stem torque/thrust (MAST) is defined as the maximum torque/thrust that can be applied to the valve train without risk of damage, as defined by the valve manufacturer/supplier. The valve train consists of all parts of the valve drive between the operator and the closure member, including the closure member but excluding the valve operator such as the gearbox. The important point is that the actuator's maximum output torque/thrust, based on the maximum supply voltage or operating pressure generated by the actuator, should not exceed the valve MAST at any point of travel. The actuator is a component or machine installed on the valve that is responsible for moving (e.g., opening or closing) the valve. This paper provides a formula for the calculation of MAST in different sections of a valve stem installed on an oil export pipeline. The result of this calculation shows that the MAST in the rectangular section of the stem is less than the actuator torque. Two solutions are proposed in this paper: one is to increase the rectangular section diameter, and the second is to upgrade the material to a higher strength option such as Inconel 718. The second solution, which is more expensive, improves the MAST of the stem in all four sections of the circular section with stem keys, stem keys, the circular section, and the rectangular section.

The stem of the valve is a critical component which transfers the loads from the operator to the valve internals. The valve stem is under a high level of stress and loads. The loads come from the valve operator, which could be the actuator or the gearbox. Valve stems are typically under stress more in the case of actuation. Actuators, especially those which work with hydraulics, can produce a high force or torque on the valve stem. Therefore, the valve stem should be strong enough to withstand the loads generated by the valve operator. The failure of a valve stem leads to leakage from the valve to the environment, as well as loss of the valve as an asset. Leakage from the valve could have other negative consequences, such as loss of human life and environmental pollution.

The paper provides a formula to calculate the maximum allowable stem torque (MAST) for the stem of a valve. MAST is a value for determining the stem's limitation as regards withstanding the loads or torques. Torque is defined as force multiplied by distance. In fact, MAST should always be greater than the force or torque generated by the valve actuator or gearbox. Typically, the stem of the valve is less exposed to the loads in the case of having a gearbox or manual operation. However, stem strength and MAST is more important in the actuated valves. There are two ways to increase the MAST; the first is to increase the stem diameter and the second is to upgrade the stem material to one with greater mechanical strength.

Conclusion

Thus, the key findings in the paper can be summarized as follows:

- Providing a method for calculation of MAST in the valve stem;
- Identifying two approaches to increase the MAST; selecting higher strength material and increasing the stem diameter.

Paper #11) A review on subsea process and valve technology

Objective

Comparing subsea valves and valves installed on a platform, in terms of standards, quality and quantity and testing. Testing is a very important parameter for subsea valves, which leads to significant improvement of their safety and reliability.

Discussion presented in paper

The world's energy consumption continues to increase steadily. Fossil fuels (oil, natural gas, and coal) still comprise more than approximately 85% of the world's energy consumption. Offshore oil field development and operation began by using platforms and ships, but oil producers and operators are looking for new and innovative ways to reduce production costs and improve recovery and production rates from reservoirs. As a result, subsea production solutions are becoming more popular. A subsea production system consists of subsea completed well(s), seabed wellhead(s), production tree(s), subsea tie-ins to flow line systems, and subsea equipment and control facilities to operate the well(s). The wellhead consists of the pressure-containing components at the surface of the oil and gas well that provide the interface for drilling, completion, and testing of the well, in addition to production equipment. Subsea manifolds are used to simplify the subsea system, minimizing the use of subsea pipeline and risers, while optimizing the fluid flow. Subsea valves, which are mainly ball or through conduit gate valves, are located on the trees and wellheads and designed based on API and ISO standards. They are made in exotic corrosion-resistant alloys, to avoid different types of corrosion, such as hydrogen-induced stress cracking, and should withstand high-pressure classes. These valves can be manual or actuator-operated with or without the help of a remotely operated vehicle. The subsea industry is shifting from hydraulic-type to electrical-type actuators for important reasons, including reduced costs and faster operation. Newly designed subsea valves should pass strict qualification tests, such as hyperbaric tests, endurance tests, and pressure and temperature cycle tests.

Conclusions

The production of oil and gas is very important, to satisfy the needs of energy consumers around the world. With the growing development of deep-water oil and gas fields, the subsea valve industry has been significantly developed and refined. Subsea valves should be maintenance-free and robust in design, to withstand the harsh marine environment. This article discussed various aspects of subsea valves, including standards, material selection and associated corrosion types, size, pressure class and temperature range, and tests. The important finding in this discussion is the recommendation to change to all-electrically actuated and operated subsea valves, to save cost and operation time, and to remove non-environmentally friendly hydraulic solutions, which will require additional research.

Paper #12) Actuator selection and sizing for valves

Objective

Selecting the best choice of actuators for the valves in the offshore industry, as well as providing a sizing method for the actuators.

Discussion presented in paper

An actuator is a machine or component installed on the top of an industrial valve to automatically move and control the valve. The performance of a valve is largely dependent on its actuator. Three factors are important for engineers to consider when selecting an actuator: frequency of operation, ease of access, and critical functions. Valve actuators should perform several functions, including moving the valve closure member to an appropriate position, holding the valve closure member in the desired position, providing enough force or torque to seat the closure member and meet the required shutdown leakage class, providing fully open or fully close or failure mode as is, or providing a certain amount of closure member rotation at the right speed. In general, the actuator can be hydraulic, pneumatic or electrical. This paper discusses the mechanism plus the advantages and disadvantages of these three types of actuators. The affected parameters for actuator selection include the availability of a power source, torque and size of the valve, failure mode, speed of operation, frequency and ease of operation, control accessories, hazardous area, and cost. This paper presents a case study of a breakaway torque (break to open) calculation and actuator sizing for a full-bore ball valve in pressure Class 300, equal to 50 barg nominal pressure and 22Cr duplex body material. The valve is fail close with an emergency shutdown function, and a pneumatic actuator was selected for the valve. Fail close means that the valve will close in the case of losing the power used as a source of actuator operation. Four other torque values were provided by the valve supplier. The calculated breakaway valve force and torque were used as a basis for actuator air cylinder sizing, assuming air pressure of 7 barg and system efficiency of 90%. Force and torque for closing the valve were used to calculate the spring movement, as well as the spring piston length through Hooke's law.

Selection of actuator type is also important in the offshore industry. Electrical actuators are just used for ease of operation. Think about a very large-size and high-pressure class valve which may need the effort of an operator for 30 minutes to close or open the valve. In this case, electrical actuators can reduce the operator man-power for operation of the valve. In addition, electrical actuators can be operated from long distances, such as the control room. Pneumatic actuators could have priority over hydraulic actuators, as they use air. Using air is a more environmentally friendly solution, compared to oil, for the actuators. However, the air pressure is typically and relatively low in the range of 5 bar to 7 bar. In some cases, when the valve is large and in the high-pressure class, a pneumatic actuator cannot produce enough force or torque for the valve operation. Therefore, hydraulic actuators which are pressurized with 160 bar to 200 bar hydraulic oil should be selected for the valve operation when the pneumatic actuator cannot produce sufficient force. The wrong selection of actuators puts the valves' performance at high risk. As an example, a valve with emergency shutdown function has a pneumatic or hydraulic actuator. Electrical actuators are not fast closing and opening, so they should not be selected for emergency shutdown valves.

Conclusions

The importance of this research is to size the actuators on the valves correctly, to produce a sufficient force or torque. Undersized actuators do not produce enough force or torque for operation of the valve. If the valve is not operable, the valve cannot perform the job in a safe manner. Let us suppose a blow down actuated valve is installed on the top of a separator to release the extra pressure in the separator. If the actuator of the valve cannot open the valve, the high pressure in the separator cannot be released, and the separator will be at risk of explosion. As another example, think about an actuated isolation valve prior (upstream) to a heat exchanger. Due to failure of the heat exchanger tube, the cold seawater used for cooling enters the shell and causes corrosion of the shell. In this case, the isolation actuated valve should be closed quickly, to stop the flow of seawater (cooling medium) to the heat exchanger. If the actuator cannot close the upstream isolation valve, the seawater flows inside the heat exchanger and causes more corrosion and complete cracking of the heat exchanger. If the actuator is oversized, it produces a high amount of torque, which can damage the valve stem and internals.

Paper #13) Challenges associated with the bypass valves of control valves in a seawater service

Objective

Selection and sizing of the bypass valves of the control valves, to maintain safety, reliability and cost reduction.

Discussion presented in paper

Modern processing plants use a variety of control loop networks to deliver a finished product to the market. Such control loops, like control valves, are designed to keep process variables, such as pressure, temperature, speed, flow, etc., within the appropriate operating range and to ensure a quality product is produced. All control valves have a bypass, so that production can proceed if maintenance is needed for the control valve as part of the control loop. The important point is that, in both operation and maintenance situations, the bypass valve and the control valve should have approximately the same flow capacity to provide nearly the same amount of pressure. This paper presents a case study in seawater service on the selection of manual bypass valves for a 16" control valve in class 150 and titanium material. A 16" butterfly valve of class 150 was chosen for the control valve bypass, which provided a much higher flow capacity than the control valve. In this paper, four solutions are recommended to achieve the same coefficient value (C_v) for the control and bypass valve. Using the reduced-size butterfly valve could be the cheapest and best solution. On the other hand, selecting the same control valve for the bypass line is the most expensive but maybe the most reliable solution. Using a flow orifice for throttling could be ranked as the second most expensive option and the second most reliable one. Selection of the butterfly valve for throttling is the second cheapest option, but it has the least reliability, considering different parameters, such as size and weight saving, cost and reliability.

Conclusion

Control valves are essential parts of a control system; they require regular maintenance. The control valve bypass should be used for operation in the case of control valve maintenance. The wrong valve selection for the bypass line of the control valves could supply too little or too much flow, compared to desired flow rate. Deviation in supplying the required flow rate could cause process problems. Therefore, the selection and sizing of the bypass valve of the control valve, which is addressed in this paper, is important. Some of the proposals for achieving the correct bypass valve selection for a control valve have been reviewed in this paper.

Paper #14) Wafer design valve verification based on ASME B16.34

Objective

This paper has a greater focus on selecting more compact and lighter and less costly valves, which is important in the offshore industry, due to the limitation of space and weight on the platforms

Discussion presented in paper

A flange connection is a very common method for attaching a valve to a pipe. The flange is a ring-shaped device designed to be used as an alternative to welding or threading various piping components, including valves. A wafer design is defined as a flangeless design with facing that permits installation between ASME and manufacturer standard (MSS SP) flanges. One advantage of using a wafer design instead of a flanged end design is that smaller face-to-face dimensions save space, and the weight and cost of the valve are lower. This paper compares face-to-face wafer-type valves and double flange butterfly valves in class 150 and size ranges between 4″ and 20″, designed according to API 609

(American Petroleum Institute 2004). Using wafer-type butterfly valves as per API 609 is very common in the oil and gas industry. However, it is not common to use a wafer-type ball valve to save weight and space. This paper reviews a case study of a wafer ball valve design, including the flange bolt holes inside the body and the closure. The criteria in the ASME B16.34 standard regarding the minimum allowable wall thickness of the valve were used to verify this design (American Society of Mechanical Engineers 2004). Therefore, this case study can provide a good guideline for verifying the design of wafer-type ball valves with the bolt holes inside the body, as per the ASME B16.34 criteria (American Society of Mechanical Engineers 2004).

Conclusion

This paper presents a comparison of the valve face-to-face wafer-type and double flange butterfly valves in class 150 and size ranges between 4″ and 20″ designed according to API 609. This paper reviews a case study of a wafer ball valve design, including the flange bolt holes inside the body and the closure. The criterion in the ASME B16.34 standard regarding the minimum allowable wall thickness of the valve were used to verify this design. (American Society of Mechanical Engineers 2004). Avoiding using this criterion for validation of the wafer-type design could lead to failure of the valve, jeopardizing the safety and reliability of the valve as well as the plant.

Paper #15) Requirement and calculation of corrosion allowance for piping and valves in the oil and gas industry

Objective

Prediction of the carbon dioxide corrosion on piping and valves, to consider a sufficient corrosion allowance as an extra thickness to the valves, in order to mitigate this type of corrosion.

Discussion presented in paper

"Acid gases" refer to two of the undesirable by-products of oil and gas, namely CO_2 and H_2S. The reaction of H_2S and other sulfur compounds with water increases the degree of "sour corrosion", by forming sulfuric acid. CO_2 corrosion of carbon and alloy steels is designated "sweet corrosion", which is defined as the deterioration of metal components resulting from contact with gas or solutions including both CO_2 and water. CO_2 corrosion is an important problem in the oil and gas industry, due to metal loss and its severe effects in terms of localized corrosion. The accurate prediction and modelling of CO_2 corrosion rates for carbon and alloy steel pipes are vital tasks at the basic design phase of oil, gas and petrochemical projects, in order to determine whether to consider additional wall thickness for the pipes and valves, defined as a "corrosion allowance" (CA), or to change the pipes' or valves' base materials to "corrosion resistant alloys" (CRA). Other corrosion mitigation approaches, such as injecting the corrosion inhibitors and glycol or methanol, can reduce the metal loss and CO_2 corrosion. This paper proposes a practical model to calculate and select the corrosion allowance for piping and valves in the oil and gas industry. Different process parameters, such as scaling, fugacity, PH, glycol and corrosion inhibitor injection, water cut, operating pressure and temperature, as well as CO_2 partial pressure, have been applied in the model.

Conclusions

As hydrocarbons emerge from subsurface geological formations, they carry water and acid gases that need to be separated from the main product prior to transportation to the refineries. The internal corrosion attack on pipelines and equipment, due to wet corrosive media activating CO_2 and H_2S and other sulfur compounds, is a long-term and commonplace adverse issue in the oil and gas industry. CO_2 corrosion of carbon and alloy steels is designated “sweet corrosion”, which is defined as the deterioration of metal components resulting from contact with gas or solutions including both CO_2 and water, since CO_2 is non-corrosive in the absence of water. It leads to loss of material and pitting in the production, transportation and processing facilities, including piping and valves. This is of special concern and severity where carbon steel and low alloy steel are used. The accurate prediction and modelling of CO_2 corrosion rates for carbon and alloy steel pipes are vital tasks at the basic design phase of oil, gas and petrochemical projects, in order to determine whether to consider additional wall thickness for the pipes and valves defined as “corrosion allowance” (CA) or to change the pipes’ or valves’ base materials to “corrosion resistant alloys” (CRA). The most widely recognized CO_2 corrosion prediction modelling is the “DeWaard and Milliams Model”. This paper proposes a practical model to calculate and select the corrosion allowance for piping and valves in the oil and gas industry. Different process parameters, such as scaling, fugacity, pH, glycol and corrosion inhibitor injection, water cut, operating pressure and temperature, as well as CO2 partial pressure, were applied in the model.

Paper #16) Optimized valve stem design in oil and gas industry to minimize major failures

Objective

Focusing on some essential design considerations for the stem of subsea valves, to prevent failure of the stem during operation. The stem is counted as a pressure-containing part of the valve, which means that its failure to function leads to leakage of the fluid inside the valve to the environment.

Discussion presented in paper

The importance of the valve stem has been reviewed in Paper #10. The stem of the valve transfers the load from the valve operator to the valve's internals. Therefore, the stem should be strong, especially in the case of actuation, to withstand the loads generated by the valve operator. Paper #10 introduced two approaches for increasing the stem's mechanical strength: increasing the stem diameter and upgrading the material of the stem to a higher mechanical strength. However, other important aspects of stem design are not covered by Paper #10.

Paper #16 explains more aspects of stem design, such as anti-blow out and anti-static requirements. Anti-blow out stem design prevents blow out of the stem to the operator in the case of removing the valve operator. Thus, the anti-blow out design is connected to HSE concerns and requirements. Anti-static design is another important aspect, which is briefly discussed in this paper to prevent static electricity in the stem, as well as its contact with the ball and the body of the valve. An accumulation of the static electricity in the valve parts, including the stem, especially when the valve handles hydrocarbon and flammable fluid, is the cause of fire and explosion. Thus, it can be stated that Paper #16's aim is to improve the design of the stem, not only against the loads but also to prevent damage to the operator, as well as fire and explosion. In fact, anti-blow out and anti-static designs for the stem of the valve, which are discussed briefly in the paper, are improving the safety and reliability of industrial valves.

Conclusion

Valve stems provide a connection between the valve operators (gear/actuator) and the valve internals. The stem is a pressure-containing part of the valve, which means any failure of this component leads to a leakage of the fluid into the environment. In addition, failure of the valve stem has other negative consequences, such as human injury or death (HSE issues), loss of assets, and fire and explosion, etc. This paper explained in detail some of the main design features of a valve stem, such as diameter calculation, MAST, material selection, and anti-blow out and anti-static design features. The valve stem sealing is not included in this article and requires separate research.

Paper #17) All electrical subsea control systems and the effects on subsea manifold valves

Objective

Discussion and recommendation of the use of all-electrical subsea systems and actuators, instead of hydro-electrical systems, to increase reliability and safety, and to reduce costs.

Discussion presented in paper

Subsea development is moving constantly towards simplification, digitalization and cost-out strategies, because the exploration and production of hydrocarbons is moving toward deeper and more remote seawater areas. The use of all-electrical, instead of hydraulic, subsea technology is constantly growing and will be the future of subsea systems, due to the environmental and functional advantages, as well as cost reduction. The benefits of all-electrical subsea systems are HSE, improved reliability, flexibility and functionality, compared to traditional hydraulic-electrical systems. Existing Electro-Hydraulic Technology (EHT) for a typical subsea system, hydraulic and electrical actuators, and subsea manifold valves, including valve types and selection philosophy, are reviewed in this paper. Some major worldwide oil companies, like Equinor and Schlumberger, have successful experience of subsea electrical actuators. Considering the benefits of All-Electrical Technology (AET), especially with regard to cost and HSE, as well as the successful experience of two major oil companies, it is worth doing more research in this area. One of the gaps in the existing reviewed literature is the effect of using all-electrical actuators for the manifold valves. Thus, three main questions related to electrical actuator selection, requirement of Safety Integrity Level (SIL) and effect of using electrical actuators on the manifold valve selection are addressed and answered. Forty hydraulically actuated manifold valves, from nine past subsea projects in different parts of the world, mainly from Africa and Australia, have been selected for the analysis of all-electrical actuators. The result shows that 93% of the valves require spring return electrical actuators, whereas 7% can be operated with the conventional electrical actuators without any spring. The manifold valves do not require SIL certification, since they are not connected to the emergency shutdown system. The final conclusion is that introducing the electrical actuators to the manifold valve will not change the valve selection philosophy.

Conclusion

It has been proved that the application of all-electric instead of hydro-electric for subsea systems brings many advantages, such as HSE, reliability improvement and cost reduction. The main question which is answered in this research is how shifting to an all-electric power supply for subsea can change the valves and actuators. In fact, the main change is to shift from hydraulic actuators to electrical actuators. The key findings are that shifting to an all-electrical system means that there is no need to change the valves. In addition, subsea valves are not categorized as safety critical valves. Therefore, whether they are actuated with hydraulic or electrical actuators does not affect the SIL for these valves. SIL is explained in detail in Paper #9.

Paper #18) Subsea valves and actuators: A review of factory acceptance testing (FAT) and recommended improvements to achieve higher reliability

Objective

To review and improve the factory acceptance test for subsea valves and actuators, to improve their safety and reliability.

Discussion presented in paper

Oil exploration is constantly moving into deeper waters. The costs associated with downtime and the maintenance of facilities and equipment such as valves and actuators, collectively known as Operation Expenditures (OPEX), are very high in the offshore sector of the oil and gas industry, particularly the subsea sector, where water depth may reach 1–3 km. Subsea valve and actuator failures contribute to other negative consequences, for example loss of production and HSE issues, such as environmental pollution as a result of oil spillage. Therefore, more reliable subsea equipment, including valves and actuators, is required in the industry. The reliability of valves and actuators is largely dependent on testing, especially factory acceptance tests (FAT) and qualification test programs. This paper reviews 12 existing tests, based on international standards such as the API standard and the ISO standard for valves, actuators and manual gear overrides. Different types of tests, such as pressure tests, function tests and operation characterization tests, are included in this review. Parameters such as test pressure and duration, test preparation and methods for test implementation are discussed. Eight additional tests are proposed in this paper, on the basis of industrial experience, to minimize the failure rate of expensive subsea equipment and to increase its reliability.

Conclusion

In general, three main factors can improve the reliability and safety of subsea valves and actuators, according to the current literature. The first is exotic and corrosion-resistant alloys for subsea valves, which are discussed in Paper #1. The second is accurate and strict testing, which is reviewed in this paper. The third is very tight manufacturing tolerances, which are proposed as a future research topic. Different tests applicable to valves and actuators have been reviewed. Some improvements have been proposed to the existing tests, and some new tests have been proposed, to improve the safety and reliability of the valves and the actuators.

Paper #19) Development of a numeric method to validate the reliability improvement of safety critical valves during operation through online monitoring implementation

Objective

Validation and measurement of reliability improvement for safety critical valves during operation, through implementation of the safety critical valves.

Discussion presented in paper

Online valve monitoring, also called “ValveWatch,” is a state-of-the-art method for improving the reliability of safety critical valves during operation. This well-known method has been used for almost two decades to reveal the possible failures of valves, actuators and control systems. This paper reviews some of the existing literature about ValveWatch technology to provide more detailed information about this online monitoring approach and its benefits. The main objective of this research is to provide and describe a numeric measurement approach to estimate the probability of failure detection in a system including a valve, an actuator and a control system, through online condition monitoring, and compare it with probability of failure detection in the system with visual inspection but without any online condition monitoring. To achieve the objective, 19 possible failures associated with a valve, an actuator and a control system are identified in this paper. Three main sensors which are the essential components of online condition monitoring are identified. The probability of each failure detection, from zero to one hundred percent for each type of sensor, is identified. The probability of each failure detection from zero to one hundred percent is identified in another scenario, in which no online condition monitoring is implemented. The second scenario’s main focus is to identify the probability of failure detection through a visual inspection. The result of these two scenarios is compared, to evaluate and determine in a quantitative manner the effectiveness of online condition monitoring implementation in detecting possible failures on an actuated valve during operation. All these activities have been carried out in order to prove, through a numeric approach, that using online monitoring significantly improves the safety and reliability of the actuated valves, as well as the plant, by increasing the probability of failure detection in the valves and actuators.

Conclusion

ValveWatch technology has been used in the oil and gas industry, especially offshore, to improve reliability and minimize the occurrence of undesirable events. The advantages of ValveWatch can be summarized in four categories: reducing operational cost, improving HSE, strengthening valve technology and that of connected instrumentation (actuator) and control systems, and increasing compliance with regulations. The different main operational problems associated with valves, actuators and control systems have been identified, and the probability of detecting these defects through visual inspection and online monitoring has been evaluated. The results show that the probability of failure detection, also called diagnosis coverage, can be improved from the 28.4% achieved by visual inspection to 95.8%, by using online condition monitoring. This is more than a 3.5 times improvement. The research in this paper is limited to safety critical valves. It is proposed that future work be carried out on pressure safety valves, as well as check valves, to measure reliability improvement by using the ValveWatch system. In addition, based on this paper, the possibility of failure detection for online monitoring of safety critical valves is 95.8%. Separate research is proposed to improve the reliability of online condition monitoring for safety critical valves.

4. Conclusions

4.1 Key findings

The key findings of the 19 approved and published papers summarized in the literature review are listed in this section:

1. Optimum material selection for subsea valves **(Design optimization and corrosion prevention through suitable material selection leads to valve safety and reliability improvement and OPEX reduction)**

2. Introducing and applying a state-of-the-art method for design optimization and weight-saving of pipeline valves in the offshore industry, by using the calculation method given in ASME Sec. VIII Div.02(American Society of Mechanical Engineers 2012). **(Design optimization through weight- and space-saving for pipeline valves leads to CAPEX reduction)**

3. Addressing cavitation as a main operational problem for globe valves and providing solutions to mitigate this risk (**Design and valve selection optimization to reduce OPEX)**

4. Evaluation of the valves' sealing and operability in case of fire, through thermal analysis (**Design validation and HSE improvement for valves to reduce OPEX)**

5. Identification of main risks associated with pipeline valves and quantifying them, as well as proposing mitigation approaches through a systematic method such as FMEA **(Reducing OPEX and increasing safety and reliability)**

6. Designing the check valves based on minimum flow, to avoid operational problems like chattering of the check valves **(Design optimization for check valves to reduce OPEX)**

7. Improvement of the integrity of the valve and actuator (automatic operator) against different loads such as blast, through a case study, and minimizing the chance of breakage between valves and actuators **(Design optimization for valves and actuators to reduce OPEX)**

8. Noise and fatigue analysis in the valves **(Valve design and HSE improvement)**

9. Applying Safety Integrity Level (SIL) for emergency shutdown valves with a high degree of safety expectation, to evaluate and reduce the possibility of failure for these valves **(Valve design and HSE improvement to reduce OPEX)**

10. Developing a practical model to ensure that the stem of the valves, as a pressure-containing part which transfers the loads from the valve operator to the valve internals is robust enough. In addition, considering more design features for the stem of the valve, such as anti-blow out and anti-static, to improve the safety and reliability of the valves **(Valve design improvement to reduce OPEX and maintain higher safety and reliability)**

11. Design and selection improvement for bypass valves of the control valves, to optimize and improve process efficiency (**Design and valve selection optimization to reduce both CAPEX and OPEX)**

12. Development of a numeric model to evaluate using wafer-type ball valves as a lighter, more compact and less costly choice, compared to the flanged end type of connection **(Design optimization for valves through weight-saving to reduce CAPEX)**

13. Developing a model to calculate corrosion allowance for carbon steel valves **(Corrosion prevention as a part of material selection and design optimization leads to OPEX reduction)**

14. Shifting to all-electrical actuators to improve the efficiency and HSE for subsea valves **(Selection optimization, which leads to lower CAPEX, improving efficiency and HSE)**

15. **Improving the testing for subsea valves and actuators in order to increase safety and reliability, which leads to OPEX reduction**

16. **Strong recommendation to use online monitoring systems for safety critical actuated valves, for better detection of possible failures during operation. This approach leads to improving safety and reliability, through faster detection of failures before they become more critical.**

4.2 Proposals for future work

1. Development of model for material selection for topside valves and their components
2. Reviewing and addressing mitigation approaches for Hydrogen Induced Stress Cracking Corrosion (HISC), as well as possible analysis of HISC for subsea valves.
3. Analysis and reviewing of hyperbaric tests for subsea valves and actuators, as a part of a qualification program.
4. Addressing and analyzing the use of a closed loop system, as an HSE-friendly solution for a subsea system, and its effect on subsea actuators. The closed loop system is defined as a system in which the hydraulic oil is transferred to the topside facility and recirculated, instead of being dumped into the sea.
5. Analysis of valve sealing and packing as an important parameter in valve functionality.
6. Reviewing special design features for valves, such as double isolation and bleed, double block and bleed, etc.

7. Focusing on valve materials for seawater, such as titanium and nickel-aluminum bronze, to prevent crevice and pitting corrosion and improve reliability.

5. Addendum (List of published papers)

5.1 List of publications

1. Sotoodeh K. (2020). **Optimized material selection for subsea valves to prevent failure and improve reliability**. Journal of Life Cycle Reliability and Safety Engineering, Springer. https://doi.org/10.1007/s41872-020-00152-x

2. Sotoodeh K. (2018). **Pipeline valve technology, material selection, welding, and stress analysis (A case study of a 30 in class 1500 pipeline ball valve).** American Society of Mechanical Engineers (ASME), Journal of Pressure Vessel Technology, 140(4): 044001, https://doi.org/10.1115/1.4040139. Paper No. PVT-18-1043

3. Sotoodeh K. (2018). **Selecting a butterfly valve instead of globe valve for fluid control in a utility service in the offshore industry (based on industrial experience)**. American Journal of Mechanical Engineering, 6(1): 27–31. DOI:10.12691/ajme-6 -1 -4

4. Sotoodeh K. (2019). **Valve operability during a fire.** American Society of Mechanical Engineers (ASME), Journal of Offshore Mechanics and Arctic Engineering, 141(4): 044001, https://doi.org/10.1115/1.4042073. Paper No. OMAE-18-1093

5. Sotoodeh K. (2020). **Failure Mode and Effect Analysis (FMEA) of pipeline ball valves in the offshore industry.** Journal of Failure Analysis and Prevention, Springer DOI: 10.1007/s11668-020-00924-8

6. Sotoodeh K. (2018). **Comparing dual plate and swing check valves and the importance of minimum flow for dual plate check valves.** American Journal of Industrial Engineering, 5(1): 31–45. DOI:10.12691/ajie-5-1-5

7. Sotoodeh K. (2019). **Valves and actuators integrity and blast load calculations.** Springer Nature Applied Science, Springer Switzerland, 1, 599. https://doi.org/10.1007/s42452-019-0624-z

8. Sotoodeh K. (2019). **Noise and acoustic fatigue analysis in valves (Case study of noise analysis and reduction for a 12″ × 10″ pressure safety valve).** Journal of Failure Analysis and Prevention, Springer. 19: 838–843. https://doi.org/10.1007/s11668-019-00665-3

9. Sotoodeh K. (2019). **Safety integrity level in valves.** Journal of Failure Analysis and Prevention, Springer. 19: 832–837. https://doi.org/10.1007/s11668-019-00666-2

10. Sotoodeh K. (2019). **The importance of maximum allowable stem torque in valves.** Springer Nature Applied Science, Springer Switzerland. 1: 433. https://doi.org/10.1007/s42452-019-0445-0

11. Sotoodeh K. (2019). **A review on subsea process and valve technology.** Marine Systems and Ocean Technology, Springer. 14: 210-219. https://doi.org/10.1007/s40868-019-00061-4

12. Sotoodeh K. (2019). **Actuator sizing and selection for valves.** Springer Nature Applied Science, Springer Switzerland. 1: 1207. https://doi.org/10.1007/s42452-019-1248-z

13. Sotoodeh K. (2020). **Challenges associated with the bypass valves of control valves in a seawater service.** Journal of

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14. Sotoodeh K. (2019). **Wafer design valve verification based on ASME B16.34.** Springer Nature Applied Science, Springer Switzerland. 1: 1476. https://doi.org/10.1007/s42452-019-1344-0

15. Sotoodeh K. (2020). **Requirement and calculation of corrosion allowance for piping and valves in the oil and gas industry.** Journal of Bio- and Tribo-Corrosion, Springer. 6: 21. https://doi.org/10.1007/s40735-019-0319-4

16. Sotoodeh K. (2020). ***Optimized valve stem design in oil and gas industry to minimize major failures***. Journal of Failure Analysis and Prevention, Springer DOI: https://doi.org/10.1007/s11668-020-00891-0

17. Sotoodeh K. (2020). **All electrical subsea control systems and the effects on subsea manifold valves.** Journal of Marine Science and Application. https://doi.org/10.1007/s11804-020-00155-1

18. Sotoodeh K. (2020). ***Subsea valves and actuators: A review of factory acceptance testing (FAT) and recommended improvements to achieve higher reliability***. Journal of Life Cycle Reliability and Safety Engineering, Springer. DOI: https://doi.org/10.1007/s41872-020-00153-w

19. Sotoodeh K. (2020). ***Development of a numeric method to validate the reliability improvement of safety critical valves during operation through online monitoring implementation***. Journal of sensing and Imaging, Springer. DOI: https://doi.org/10.1007/s11220-020-00323-1

5.2 Linking the papers

This section provides more information about the logic of linking the papers together, as well as Figure 6, a chart and diagram for linking the papers.

5.2.1 Material optimization and corrosion prevention

Paper #1, which addresses the optimum material selection for subsea valves, and Paper #15, which concerns carbon dioxide corrosion modeling and prediction, are placed into one group. The main contribution of these two papers is to select the optimum materials for the subsea valves in the subsea sector of the oil and gas industry. Corrosion prevention, especially in a corrosive subsea environment, leads to an improvement in safety and reliability. Thus, these two papers improve the safety and reliability of offshore valves indirectly, through optimum material selection. Material failure in valves causes negative and costly impacts, such as loss of asset, loss of production, environmental pollution, damage to human health, etc. These two papers are highlighted in green in the diagram.

5.2.2 Design improvement

Seven papers have been categorized as those which improve the design of the valves. Paper #2 provides a method for calculating the wall thickness of the pipeline valves, as well as finite element analysis application to validate the design of the valve. Pipeline valves, which are the largest and the most important valves on offshore platforms, are used for transportation of the oil from the offshore platform to the destination. Pipeline valves are exposed to a high number of loads from the connected pipeline. Failure of the pipeline valves due to the loads stops oil production and means the loss of an expensive asset. That is the reason why load analysis is important for design improvement of these valves, which is considered in Paper #2. Paper #6 encourages the valve designers to consider the minimum flow for check valve design to prevent chattering. Chattering is a common operational problem in the check valves and jeopardizes the flow assurance and process optimization as a part of process safety and reliability. Paper #7 focuses on the integrity between the valve and the actuators, which is a part of design improvement to prevent disconnection between the valves and actuators. Valves without actuators are not operable, which puts the safety and reliability of the process and operation in great danger. Papers #10 and #16 provide some essential design considerations and improvements to prevent failure of the valve stem. As an essential valve part, failure of the stem to function leads to environmental pollution, loss of asset, loss of production and, in some cases, loss of human health or life, which is a threat to the plant's safety and reliability. Paper #12 concentrates on actuator selection and sizing for the valves on the platforms or ships, as a part of actuator design improvement. The design improvement of the actuators improves the performance of the valves. Paper #17 focuses on a hot topic in subsea: changing to an electrical source of power instead of hydraulic power. An all-electrical system improves the design, by reducing cost, improving the reliability and speed of operation, and HSE improvement. All seven papers mentioned improve the design of either valves or actuators – or both. The design improvement of the valve and actuators improves the plant's safety and reliability. Thus, all these seven papers improve the safety and reliability of plants indirectly through improving the design. These seven papers are highlighted in blue in the diagram.

5.2.3 Safety and reliability improvement

Seven papers have a direct, positive impact on safety and reliability; they are highlighted in orange in the diagram. Paper #4 focuses on the operability and sealability of the valves in case of fire. Valves should be operable after fire and provide some extent of sealing in the case of fire, to prevent complete leakage of the fluid inside the valve to the environment, to avert environmental pollution and HSE issues. Paper #8 provides a calculation method based on the available standards to ensure that the noise level inside the valve is not high. A high level of noise can cause hearing problems for personnel and fatigue stress in the valves. It can also put the safety and reliability of the valves in danger, so it should be controlled and mitigated. Paper #5 has a strong focus on pipeline valves, which are the largest, heaviest and most important valves on the platform, in the offshore industry. These valves are positioned on the gas or oil export line, which is installed to deliver the produced hydrocarbon to its destination. An FMEA has been performed to identify the main risks associated with the operation of these valves. The proposed solutions, based on industry experience, have been given in order to reduce these risks. Thus, a quantitative risk approach and reduction is the key focus of this paper, to reduce the failure risk of these valves and improve safety and reliability. Paper #9 addresses a very important concept of safety critical valves, known as the safety integrity level (SIL). Safety critical valves should have a high rate of safety and reliability because they are connected to emergency or process shutdown systems, which play an important role in the safety and reliability of plants. The probability of failure of these valves should be extremely low (e.g. maybe less than 0.01%). This paper provides a method to measure the probability of failure and SIL for safety critical valves. SIL measurement can ensure that these valves can provide an adequate level of safety and reliability. Paper #11 briefly reviews some of the tests and standards for subsea valves which should be implemented to improve safety and reliability. Paper #18 proposes additional factory acceptance tests, to improve the reliability of subsea valves. Subsea valves are installed inside the ocean and water; they should be maintenance-free and leakage-free and provide a high degree of safety and reliability during their lifetime, which, as an example, could be 30 years. Paper #19 concentrates on ValveWatch or online condition monitoring to detect the failures on safety critical valves before they become more critical and damage the valves and actuators further. A numeric method is proposed to measure the probability of failure detection from the implementation of online monitoring, compared to the traditional inspection by personnel on site. The result indicates that, compared to the traditional approach, implementation of ValveWatch significantly improves reliability.

5.2.4 Weight- and space-saving

Paper #14 reviews a real case, in the Johan Castberg project in Norway, which uses wafer body ball valves, which are more compact and lighter than standard ball valves with both end flange connections. A method based on ASME B16.34 has been implemented to justify the use of these valves. This paper provides a method for weight- and space-saving of the valves on the platforms. Paper #2, which concerns pipeline valves, can be also placed in this category, since it proposes a method for calculating the wall thickness of valves, to reduce their weight. Reducing the weight and space is essential in the offshore industry, since there is always a lack of space offshore. In addition, platforms have a limited load capacity.

5.2.5 Valve selection optimization

There is an expression in the industry: “There is no poor valve, just poor valve selection”. Thus, it is worth optimizing the valve selection in the offshore industry, to prevent possible failure, save weight, space and cost, and improve the reliability. The three papers in a light orange color are connected to the optimization of valve selection. Paper #3 proposes using butterfly valves, instead of globe valves, to save weight, space and cost, as well as preventing a type of corrosion called cavitation. This idea has recently been put into practice by Equinor. Paper #13 focuses on the valve selection for bypass of the control valves, in such a way as to reduce the cost, space and weight and maintain high process integrity. The contribution of Paper #3, to reduce the risk of cavitation as an important operation problem, leads to improving safety and reliability. Selecting a proper valve and size of valve for bypass of the control valves maintains process integrity, which has a direct impact on the safety and reliability of the plant.

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