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Anders Lemme & Helene Jakobsen Furseth

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Abstract

The “Northern Giant”, Johan Sverdrup, is the biggest oil and gas field development on the Norwegian Continental Shelf in over 30 years. The field has an expected lifetime of 50 years, where it will provide value for asset owners and society. At maximum production, the field will produce 660,000 barrels of oil per day, which will be 25% of the entire oil and gas production in Norway. Equinor is the operator of the field, which has a planned production start in November 2019.

When Johan Sverdrup is in operation, the production needs to be reliable, cost efficient and safe. To ensure a safe state for the facility, safety barriers like emergency and process shutdown systems are in place. These systems will shut down affected processes, areas or equipment should an unwanted incident occur. The shutdown can range from a single valve to a complete shutdown and evacuation of the facility.

Some of the most critical equipment regarding safety systems is the emergency and process shutdown valves, which have strict requirements regarding performance and reliability. Function and leak testing are currently the preferred method of verifying the condition of the valves. These tests are typically performed every 12 months and reported to the Petroleum Safety Authority of Norway. The testing requires resources and production downtime to be performed.

The purpose of this thesis is to illuminate the effectiveness and potential benefits by expanding the use of condition monitoring on emergency and process shutdown valves. This can increase the reliability of the valve and explore the possibility of utilizing condition monitoring to perform function and leak testing more efficiently. The thesis will also include an estimate of the potential cost saving related to a decrease in downtime due to condition monitoring.

To illuminate this potential, an analysis has been developed to match the most likely valve degradations with relevant condition monitoring equipment’s ability of indicating the degradation. The analysis was used to determine which sensors has the highest coverage degree of failures and then how the use of sensors can be expanded on Johan Sverdrup. A result matrix was developed to assist in choosing which sensors should be installed on which valves, dependent on the valve requirements and function.

A potential savings estimate has been performed to indicate the loss of revenue related to production downtime. By utilizing condition monitoring on emergency and process shutdown valves, the corrective maintenance and annual testing can be done more efficiently and therefore decrease the necessary production downtime. There is a major potential for cost savings due to the production downtime related to testing.

The results of the analysis show that most failures on automated valves can be detected by condition monitoring technology. The sensors are effective for continuous surveillance of the valves, troubleshooting during maintenance and for streamlining testing. By using condition monitoring on emergency and process shutdown valves, failures can be detected before they become so severe, they will affect the reliability of the valve as a safety barrier. Additionally, the potential savings estimate shows a potential saving of 1.31 million USD per hour of maintenance saved.

The thesis development and analysis are a case study at Equinor. Discussions and meetings with Equinor personnel and suppliers, combined with internal documentation and industry standards, forms the foundation of the thesis.

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Abbreviations

NCS	-	Norwegian Continental Shelf
ESD	-	Emergency Shutdown
PSD	-	Process Shutdown
ESV	-	Emergency Shutdown Valve
XSV	-	Process Shutdown Valve
SCV	-	Safety Critical Valve
PSAN	-	Petroleum Safety Institute of Norway
CM	-	Condition Monitoring
IOC	-	Integrated Operations Center
FMSA	-	Failure Mode and Symptom Analysis
SIS	-	Safety Instrumented System
IEC	-	International Electrotechnical Commissioning
SIF	-	Safety Instrumented Function
SIL	-	Safety Integrity Level
SAS	-	Safety Automated System
PFD	-	Probability of Failure on Demand
DU	-	Dangerous Undetected
DD	-	Dangerous Detected
FMEA	-	Failure Mode and Effect Analysis
SCE	-	Safety Critical Element
FST	-	Full Stroke Test
PST	-	Partial Stroke Test
APS	-	Abandon Platform Situation
SRS	-	Safety Requirement Specification
CCR	-	Central Control Room
VDT	-	Valve Diagnostic Tool

1. Introduction

1.1. Background

Equinor is an international energy company present in over 30 countries worldwide. The company headquarters is in Stavanger and has to date over 20,000 employees spread all over the world. They are the leading operator in oil and gas on the Norwegian Continental Shelf (NCS) where they operate more than 40 platforms. They are engaged in exploration, development and production of oil and gas, as well as keeping focus on renewable energy sources such as wind, solar and geothermal power.

Equinor was founded under the name “Den Norske Stats Oljeselskap AS”, Statoil, in 1972. In 1982 Equinor was the first Norwegian company to become an operator for a field, Gullfaks in the North Sea. The company grew fast during the 1980s by developing several large fields like Statfjord, Oseberg and Troll. [1]

Johan Sverdrup is an oil and gas field discovered in 2010 which was approved for development and operation in 2015. The topside solution chosen for the field consist of five platforms connected by bridges. [2] The reason for this solution is due to the large volume of the planned production. If the offshore installation were to be only one platform, it would be unreasonably large and expensive. The processing part of the installation is divided into two platforms. In addition, there is a separate platform for the living quarters, one for drilling and well operation and a platform connecting the risers and umbilical to the rest of the facility.

Johan Sverdrup is one of the largest oilfield discoveries on the NCS, with estimated oil reserves of 2.1-3.1 billion of oil equivalents with an ambition to produce 70% of the reserves. At peak production it is estimated to be 25% of the Norwegian petroleum production at 660,000 bbl/day. This field will be one of the most important industrial projects in Norway for the next 50 years. The Johan Sverdrup platforms will be powered by electricity from shore. This will reduce the emission of climate gases by 80-90% compared to the standard development where gas turbines are used. The produced oil from Johan Sverdrup will be transported by pipeline to the Mongstad terminal, and the gas will be exported through another pipeline to Kårstø for processing. [3]

To ensure the safety of the facility, plant and environment there are several safety barriers in place, including an emergency shutdown (ESD) system and process shutdown (PSD) system. Should an unwanted incident occur, the ESD/PSD system will shut down the affected system, equipment or area. Dependent on the severity of the incident, the shutdown could be from closing a single valve to total facility shut down.

The valves associated with the ESD system are referred to as Emergency Shutdown Valves (ESV) and valves associated with the PSD system are referred to as Process Shutdown Valves (XSV). Since these valves in many cases are interchangeable, when speaking of both ESV and XSV, they will be referred to as a Safety Critical Valve (SCV). Because of the severe consequence should the SCV fail, there are strict requirements regarding the maintenance and testing of these valves. These requirements typically include 12 monthly testing of the valve to ensure its functions according to the specified closing time and allowed leak rate.

1.2. Interest in the Project

Testing of the ESD and PSD system is required of all companies responsible for a facility in the oil and gas industry. To test the valves associated with the safety systems according to recommendations from Petroleum Safety Authority of Norway (PSAN), it is necessary to shut down parts of the facility. For some valves, only a small system needs to be shut down, and for others the entire production must be stopped.

A more elaborate Condition Monitoring (CM) program for the SCV's can decrease necessary downtime of the facility, and at the same time maintain safety and reliability required by the system. This will save oil companies time and money, and is of interest, not only to Equinor, but other operators on the NCS as well.

Within Equinor there are several departments related to the testing of SCV's. The Integrated Operations Center (IOC) in Bergen is responsible for CM on Equinors assets and are therefore very interested in the use of CM on on/off valves. The operations and maintenance teams are interested in staying ahead of a potential failure. The possibility of monitoring the health of the valve and to see the early signs of failure, will help plan the maintenance and thus decrease downtime of the affected system. In the oil and gas industry, time is money, and the management team at Equinor strive to ensure maximum production uptime.

1.3. Gaps in Current Strategy

CM on valves is constantly evolving and with a growing interest, due to digital development in the industry. Using digital valve positioners and some sensors, CM on control valves are common because they are in continuous operation and essential to maintain a stable production. On/off valves, such as SCV's, are normally not equipped with digital valve positioners, but often with some sensors for functional monitoring or as a troubleshooting tool. There is a potential for development and improvement for more continuous CM on such valves.

Searches on Google Scholar for symptom analysis, valve monitoring and sensors on valves, show that there is no existing template to sufficiently perform such an analysis. To show the effectiveness of sensors to detect failures on on/off automated valves, the analysis in Ch. 4.1 was developed.

1.4. Problem Description

ValveWatch is installed on most of the ESV's and many of the XSV's at Johan Sverdrup, in total 272 valves. A complete list of SCV's is given in Appendix A. Only five valves on the entire facility has a more complete package of sensors to achieve the maximum use of CM on an on/off valve.

The purpose of this thesis is to illuminate the effectiveness and potential benefits by expanding the use of CM on SCV's. The possibility of utilizing CM to streamline function and leak testing will be explored, as well as a potential cost saving estimate related to more efficient testing and monitoring of SCV's.

This thesis will map which failures can be detected or indicated by relevant sensors, both related to continuous CM and when testing the SCV's. Based on this, a decision matrix will be made to make it easier to match the valves with the recommended sensors, dependent on valve function and requirements.

1.5. Methodology

This thesis is a case study in collaboration with Equinor ASA. The thesis is structured in five steps:

- Overview of the system
- Failure Mode & Symptom Analysis (FMSA)
- Interpretation of the FMSA
- Matching sensors and valves
- Potential savings estimate

These five steps are used to illuminate the effectiveness of CM on SCV's, how CM can assist in streamlining SCV testing and the potential cost savings by reducing production downtime.

1.5.1. Equinor Resources

The main source of information used in this thesis is provided by the Johan Sverdrup maintenance engineering team and internal documents found in the Equinor database. Being able to talk to personnel working on the Johan Sverdrup project, gave insight into several different aspects related to SCV's. Interviews and meetings with personnel at the different departments is the basis for our analysis and discussion. They were also vital during data collection, in addition to assist in finding good documentation and other people who might be interested in the thesis.

1.5.2. Standards, Guidelines and Technical Requirements

The main requirements for all Safety Instrumented Systems (SIS) in the industry are made by the International Electrotechnical Commissioning (IEC). IEC61508 and IEC61511 are the two most relevant standards which describe requirements connected to safety-related systems. The IEC61508 is a general standard for functional safety, while the IEC61511 is more specific to the process control industry. [4, 5]

Associated with these standards, PSAN are referring to "Norwegian Oil and Gas Application of IEC61508 and IEC61511 in the Norwegian Petroleum Industry". This is a guideline (NOG 070), which is intended to help operators and other stakeholders to follow the mentioned IEC-standards. [6]

In addition to following the mentioned standards and guidelines, Equinor also has internal technical requirements and guidelines. In this context, they address subjects such as performance standards, reliability, risk, testing, inspection and management of safety critical equipment.

1.5.3. MRC Global Norway

MRC Global Norway is the supplier of monitoring equipment and technology associated with SCV's on the Johan Sverdrup project. Their brand ValveWatch includes relevant sensors, software and system packages. MRC Global Norway have provided relevant information to this thesis, both general technical information and system architecture at the Johan Sverdrup installation.

Documentation, correspondence and meetings with MRC Global helped to understand the current monitoring technology, as well as the potential of expanding the use of CM on SCV's.

2. Theory

2.1. Condition Monitoring

CM is a maintenance strategy which use sensors to monitor the health and condition of equipment. The sensors monitor the equipment continuously or when operated. When the equipment becomes damaged in any way, the sensors will detect a change in the equipment. This way it is possible to see how the equipment perform over time.

Typically, CM is used on moving or rotating equipment, like turbines, compressors and pumps. Control valves, which regulates the flow through a pipeline, often has a digital valve positioner to help detect functional failures, because it is operated continuously. On/off valves, such as SCV's, is usually not operated on a regular basis. Because of their intended function and operation frequency, they are normally not equipped with digital valve positioners, but often with some sensors for functional monitoring or as a troubleshooting tool.

CM on valves utilizes sensor attached to or near the valve and actuator assembly to monitor and record their performance, as seen in Figure 1. Strain sensors and actuator pressure sensors monitor the valve and actuator performance during operation, while dynamic pressure sensors and acoustic sensors monitor the valve for internal leaks. Together these sensors provide operators an automated check-up on the condition of the valve and actuator package.

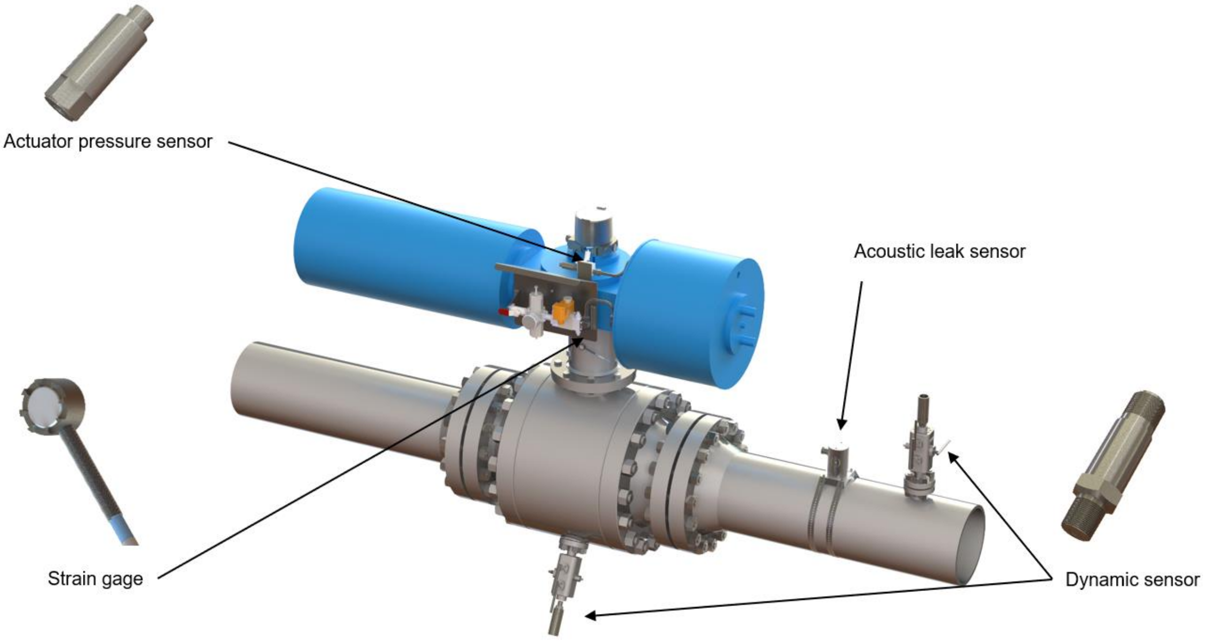

Figure 1 - Examples of ValveWatch sensors and where they are placed [7]

The sensors provide valuable diagnostics data of the valve. Problems with the operation of the valve, including damage to valve and actuator components, will be detected by the sensors. The set-up of the CM program varies depending on the process parameters of the system and size and configuration of the valve and actuator. [8]

The actuator pressure sensor is mounted on the pressurized section of the actuator. The sensor is available in different pressure ratings to ensure optimal scaling. [7]

The strain sensor is used to monitor the mechanical performance of the actuator and valve. It is installed directly on the yoke. It measures the dimensional changes by analyzing the amount of force or torque acting between actuator and valve. This type of sensor measures stem torque on ball valves. [7]

The dynamic pressure sensor detects leaks in the pipeline and the sealed cavity in the valve by using two or three pressure sensors. They can be mounted upstream, downstream or in the cavity of the valve. The sensors will compare the pressure in two or more locations to determine if there is a leak. This data can be used to confirm the integrity of the seal. [7]

The acoustic sensor is a non-intrusive sensor that is mounted downstream pipeline from the valve or on the valve body. The sensor detects leakages through the blocking element of the valve when it is in closed position, by detecting a difference in pressure across the valve. It can operate in flow regimes such as oil, water, gas and multiphase. [7]

2.2. ESD System

An ESD system is designed to stop operations of the process and isolates it from the rest of the plant should an unwanted event occur. In this way, the likelihood of an unwanted event occurring, continuing or escalating is reduced. The main purpose of the ESD system is to protect personnel, plant and prevent damages to the environment caused by a process event.

The ESD system differentiates from the other safety systems, because it responds to threats to the entire facility, not only locally in a system. It is therefore considered one of the most important safety systems that can be provided for any facility. Without an ESD system, an incident at a processing facility can yield “unlimited” fuel which can destroy the entire facility. An ESD system is designed with these minimum design requirements:

- A shutdown reverts the process to a safe state
- It prevents subsequent process operation until the cause of the shutdown has been corrected

- Preventing unintended process startup until correction of the shutdown [9, p. 216]

Most ESD systems are designed with several mechanisms which can initiate a shutdown. These mechanisms can be initiated both manually and automatically. The mechanisms can be:

- Manual activation from a main facility control panel
- Manual activation from a strategically located initiation station within the facility
- Automatic activation from a confirmed fire and gas detection alarm
- Automatic activation caused by process instrumentation alarms
  [9, p. 217]

The activation logic for an ESD is kept as simple as possible. Usually there are specific levels of ESD activations. These levels activate emergency measures with increasing amounts or areas of the facility as the incident involves a larger and larger area or hazard posed by the initial event. Low hazards or small area involvement would only require a shutdown of individual equipment, while major incidents would require a plant shutdown. The isolated portion of the facility should not pose a threat to another portion of the plant, if so it too should be shut down. Typical ESD levels used in the oil and gas industry are shown in Table 1.

Table 1 - Typical ESD levels

ESD level	**Action**	**Criticality**
1	Total facility shutdown	Catastrophic
2	Unit or plant shutdown	Severe
3	Unit or equipment shutdown	Major
4	Equipment protective system	Slight
5	Routine (non-ESD) alarms	Routine

A total facility ESD shutdown shuts down the entire facility under emergency conditions. On a lower level, a unit shutdown isolates a process unit, process train or area involved in a fire or emergency, thus limiting the supply of fuel. Although it would be easy to institute a total plant shutdown for every incident, it would not be cost effective, because small incidents occur much more often than large incidents. The smaller incidents would not warrant the shutdown of the entire facility and would reduce the economic return of investments, due to lower production. [9, p. 218-220]

The ESV controls the process medium flow and is responsible for isolating the supply of hazardous gasses and fluids within the pipeline in the event of an emergency. As a result, these valves require a more reliable performance than standard on/off valves. Since the ESV remains in operating position (open or closed) for long periods of time, the system performance and reliability is checked periodically. [10]

2.3. Emergency and Process Shutdown Valve

The valve, including actuator and local control panel, is the final element which physically stops the medium when a shutdown is required. The general intention of all valves is to control (direct or regulate) the flow through a process. An SCV is an on/off valve which means it is usually operating either in a fully open or fully closed position. A typical control valve is intended to regulate the flow, pressure or temperature of the process medium. This kind of valve is not necessarily designed to completely stop the medium flow. [11]

An XSV is intended for normal process shutdowns, while an ESV is the system protection when an emergency occurs. The main difference between an ESV and XSV is that the ESV is part of a Safety Instrumented Function (SIF) and its related Safety Integrity Level (SIL). An ESV can in some cases be used as an XSV, using a separate control unit for the process shutdown function. A typical shutdown valve is in open position under normal process conditions and travels to a closed position when system/process protection is needed. Some SCV's are closed during normal operations and works in the opposite way, depending on the connected process. [11]

2.4. Valve Construction

In an oil and gas context, an on/off valve can be divided into the following main components: Valve body, body joints, bonnet, stem, blocking element and seats. This is illustrated in Figure 2.

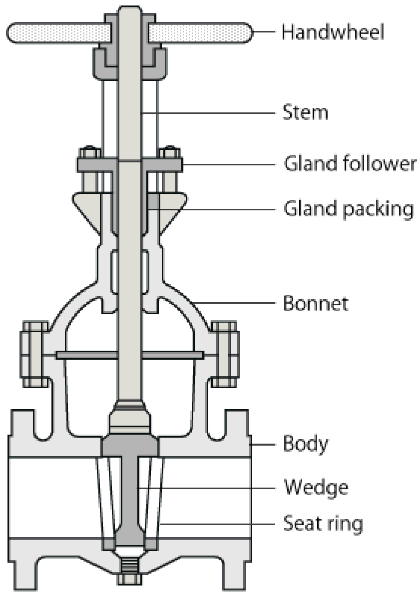

Figure 2 – Typical parts of a valve [12]

2.4.1. Valve Body

The valve body is the physical boundary between the inside of the valve and the atmosphere. It keeps the medium inside the valve and keep all valve parts together or in their intended positions. The valve body parts are normally casted or forged, and are assembled using bolts, clamps, threads or welding techniques.[13]

2.4.2. Body Joints

The body joints are the two valve openings on the valve body where the medium flows in (upstream) and out (downstream) of the valve, when in an open position. They connect the valve to the rest of the system, like pipes, pumps, valves or other parts of the process. [13]

2.4.3. Bonnet

The bonnet is connected on top of the pressurized valve body and supports the stem, stem sealing and possibly a yoke or pedestal for an actuator. It is typically attached to the valve body by bolts, threads or welding. [13]

2.4.4. Stem

The stem is the connecting part between the valve's blocking element (inside) and the actuator or handwheel (outside of the valve). It is configured as a shaft which transfer torque or axial forces from the actuator to the blockage element, to operate the valve. [13]

2.4.5. Blocking Element

The blocking element controls the flow and is a component located internally in the valve body. It is normal to name the valve type by the design of the blocking element. The blocking element in a ball valve, gate valve and plug valve are respectively called ball, gate (wedge) and plug. [14, p. 19-20]

2.4.6. Seats

The seats are the sealing mechanism which prevent the medium to flow past the blocking element. One often distinguishes between soft and hard seats, depending on the material. Soft seats are typically made in PTFE or PEEK and hard seats are made of duplex, tungsten carbide (coated) or other metal alloys. Valves with soft seats normally have stricter requirements for internal leakage but are more sensitive to particle contaminated mediums. Hard seats on the other hand, cope better with mediums with impurities, extreme temperatures, high differential pressure or chemical attack. The downside to hard seats is that they are more vulnerable to internal leakage against the blocking element. Valve seats can either be fixed or floating. For floating valve seats, they are often preloaded with springs which push the seats against the blocking element. [14, p. 21]

2.5. Sealing Mechanisms

One often distinguishes between sealing mechanisms which are mechanical, or pressure induced. To the left in Figure 3 below, the axial force from the stem creates a sealing mechanism between the blocking element and the seats (red color). This is a mechanical sealing mechanism because it is not dependent on the upstream pressure. To the right in Figure 3, the upstream pressure “pushes” the blocking element towards the downstream seat, and the sealing is created by the pressure. [14, p. 23-31]

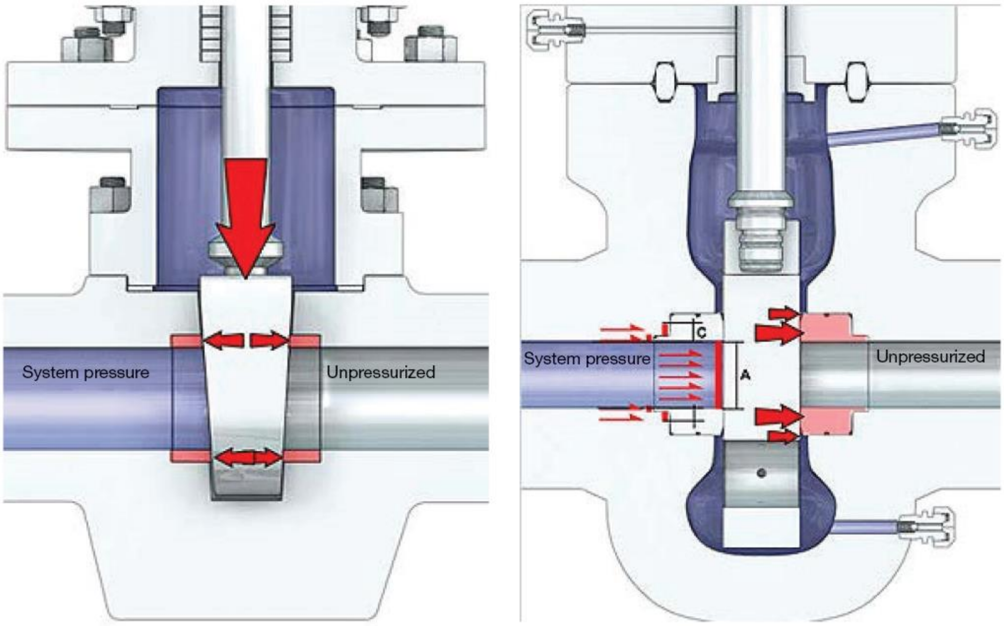

Figure 3 – Mechanical (left) and pressure induced (right) sealing mechanisms [15, p. 20]

The most normal sealing configurations related to on/off-valves are stem sealing/gland packing and body gasket.

2.5.1. Stem Sealing

The stem sealing, or gland packing, should prevent a leakage between the stem and the bonnet. Most stem sealings are graphite packings, O-rings, V-ring/lip seal and packing or a combination of these. The location of a stem sealing is shown in Figure 4. It must be tight enough to prevent a leakage, but at the same time not so tight as to prevent the valves function or create unnecessary wear. The most common hydrocarbon leakages associated with valves on the NCS are related to stem sealings. [14, p. 28]

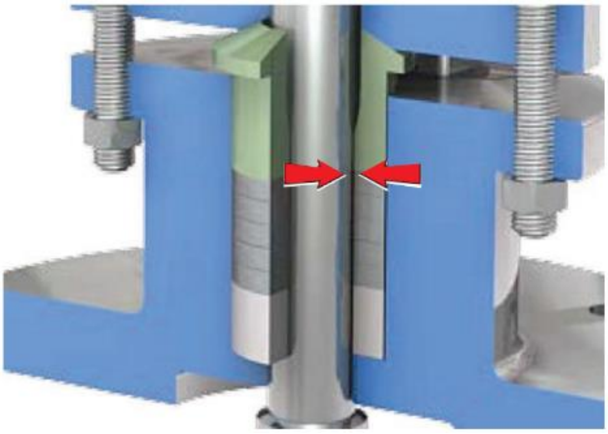

Figure 4 – Stem sealing to prevent external leakage [15, p. 28]

2.5.2. Body Gaskets

The body gaskets are the remaining sealings between the valve body parts (outer sealings) or between the inner parts (valve trim). [13, p.23, p. 43-48]

2.6. Ball Valve

A ball valve has a ball shaped blocking element which rotates 90 degrees when the valve is operated. The ball has a through hole, which is in the flow direction when open, and turned perpendicular across the flow direction when the valve is closed. Most ball valves have one seat on each side of the ball, and can seal on one or both seats, primarily depending on the seat design. Ball valves are normally divided into three main categories; floating ball, trunnion ball and no-contact/eccentric ball. [14, p. 74]

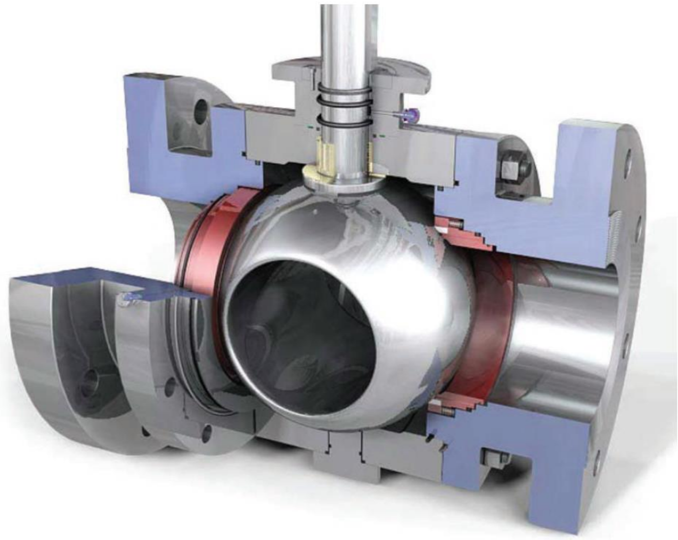

Figure 5 – Ball valve [15, p. 25]

2.6.1. Floating Ball

The ball is free to move between the seats, relative to the flow direction. Simplified, one can say that such ball valves normally seal on the downstream seat but can in some cases also seal on the upstream seat. To the left in Figure 6, the system pressure pushes the floating ball towards the downstream seat. Floating ball-designs are most common on lower pressure classes and valve sizes, because of the seat force from the ball increases significantly with the ball diameter and pressure. Additionally, a large diameter ball needs more support because of the increasing weight. [13, p. 74, 16]

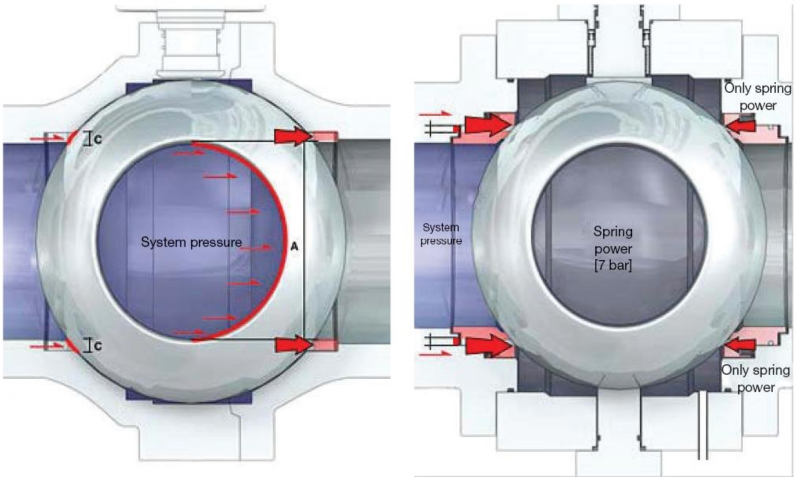

Figure 6 – Floating ball valve (left) with single acting seat and trunnion ball valve (right) with double acting seats [15, p. 20]

2.6.2. Trunnion Ball

The ball is supported by a trunnion, a support stem which is placed on the bottom of the valve body. In this way, the ball is supported between the stem and the trunnion. Trunnion ball designs have floating seats, which seals against the ball in a closed position. Both the upstream and downstream seat can be the main sealing, dependent on the seat design. To the right in Figure 6 above, the system pressure pushes the upstream seat towards the trunnion supported ball. [14, p. 76]

2.6.3. No-Contact Ball

No-contact ball valves, or also called eccentric ball valves, have a trunnion ball, but are designed to handle differential pressure better than traditional ball valves. When operated, the sealing surface on the ball are moved away from the seats at the same time or before the ball rotation starts. It is therefore no “sliding” motion between the seats and the ball, and the differential pressure is equalized without damaging the seats. The pressure is thereby distributed over a bigger area. [14, p. 84]

2.7. Actuator

To operate a valve either a handle, handwheel, actuator and/or a gearbox is needed. A valve actuator is a physical device which is intended to operate the valve with torque or axial forces. The actuator is mounted on a pedestal or bracket on top of the valve. When operating the actuator, the valve-actuator connection moves the stem, which again moves the blocking element in the valve. An actuator and its control unit are often categorized due to their "fail" functions or how they are powered. The fail function is dependent on the consequence of a power or signal loss to the actuator, and is either fail-open, fail-close or fail-in last position (remain). When a power or signal loss occurs for a fail-open actuator, the actuator will immediately travel to fully open position. It is the same principle for a fail-close actuator, which will travel to a fully closed position. All SCV's have either a fail-open or fail-close configuration, dependent on their function in the process when an ESD or PSD is activated.

The most common actuator types in a SCV context, categorized by power source are pneumatic and hydraulic. [14, p. 34-35]

2.7.1. Pneumatic

Pneumatic actuators use an air signal as input to operate the connected valve. The air pressure pushes a piston inside a cylinder or a diaphragm configuration to move the stem and blocking element. A pneumatic actuator can either be single- or double-acting, respectively if air pressure is moving the piston in one or both directions. Normally a single-acting pneumatic actuator use air pressure in one direction and one or more springs in the opposite direction. The differential force between the spring force and the pneumatic pressure force creates the actuator movement. An actuator with a fail function, use the spring force to move in the fail direction. In this way, the valve will stroke to its fail position if the actuator has a power or signal loss. [14, p. 34-35]

2.7.2. Hydraulic

A hydraulic actuator is functioning the same way as a piston configured pneumatic actuator, but with hydraulic oil pressure instead of air supply. Normally hydraulic actuators have a higher design pressure and a smaller cylinder diameter, compared to a pneumatic actuator with a similar operating torque or force. Hydraulic actuators could also be either single- or double-acting. In Figure 7 below, a single acting hydraulic actuator with spring return is shown. The blue arrow illustrates where the oil is drained when the spring force is higher than the hydraulic pressure force. The red arrow shows the hydraulic supply when the hydraulic pressure force is higher than the spring force. [14, p. 34-35]

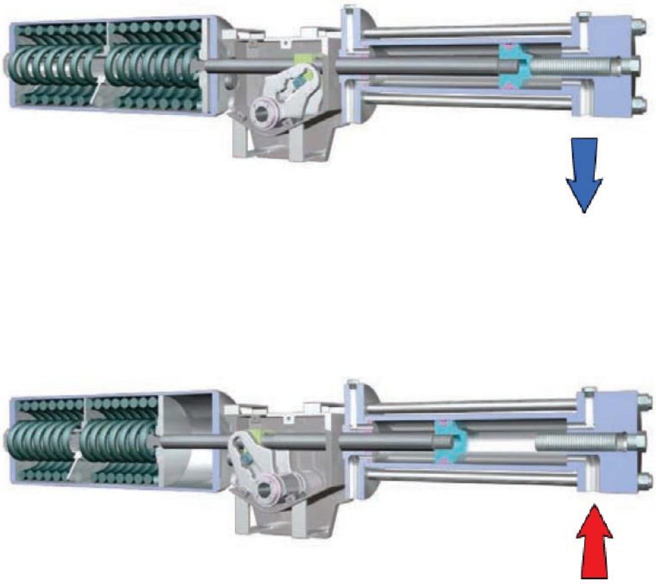

Figure 7 – Single acting hydraulic piston actuator [15, p. 35]

2.7.3. Actuator Control System

The actuator control system manages the operations of the actuator. In a pneumatic actuator the control panel use an electronic control signal and air supply as input, and pneumatic control signal to the actuator as output. The main components in an actuator control system are filter regulator, solenoid valve and limit switch, as shown in Figure 8.

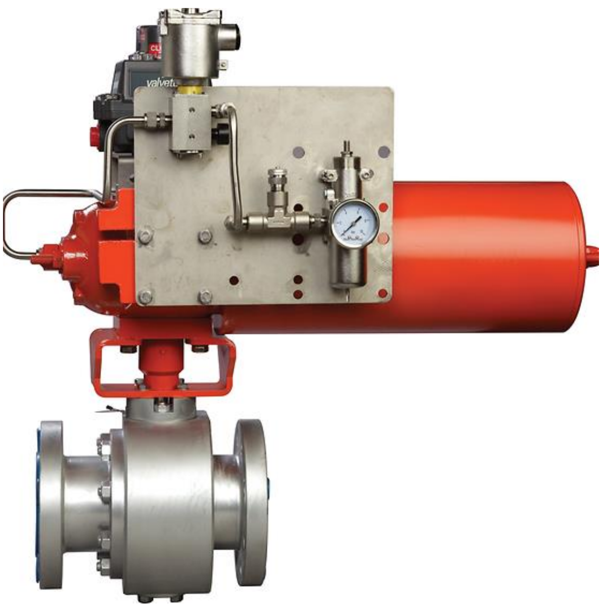

Figure 8 - Example of XSV actuator control unit showing solenoid and filter regulator [17]

Filter Regulator

A filter regulator or supply pressure regulator processes the utility medium (air or hydraulic oil) before entering the rest of the actuator control system. The processing normally consists of regulating and reducing the supply pressure and filtering of impurities and moisture. It is normally equipped with an adjustment screw, pressure gauge (manometer), filter, and moisture drain ventilation. An example is shown in Figure 9. [18]

Figure 9 - Filter regulator with pressure gauge, top adjustment screw and drain vent [17]

Solenoid Valve

A solenoid valve, or a solenoid, is an electrically operated instrumentation valve placed after the filter regulator. The purpose is to control the supply medium to the actuator, by using an electric signal to a coil as input. Usually the input signal is 4-20 mA, controlled by a programmable logic controller or similar configuration. In Figure 10 below, the main components of a solenoid valve are shown.

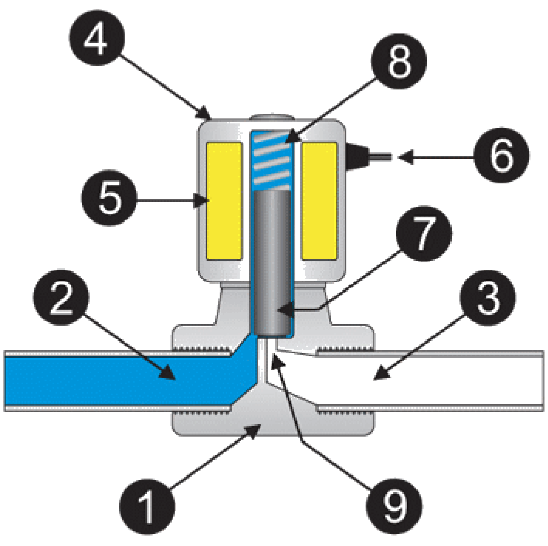

Figure 10 - Cross sectional illustration of a non-energized solenoid valve. 1: Solenoid valve body 2. Inlet 3. Outlet 4. Coil 5. Coil windings 6. Input wires 7. Blocking element 8. Spring 9. Orifice. [19]

For a single acting actuator, a solenoid valve normally has a fail-close configuration. Thus, under normal process conditions the coil is energized, and the solenoid valve is in open position. The supply pressure through the solenoid valve creates a force in the actuator which is greater than the counteracting actuator spring force. Subsequently to operate the SCV, the signal to the solenoid valve is changed and the actuator spring force overcomes the decreasing/removed utility pressure force. This way the whole actuator configuration can be operated remotely, either automatically or by an operator. [19]

Limit Switch

A limit switch is an electromechanical switch used as a feedback to determine if a valve is in an open or closed position. For a ball valve, the limit switch is connected on top of the actuator, to monitor the rotating motion of the operating actuator. This is used as a feedback for the installations automatic process system and control room operators. Additionally, limit switches often have a local visual position indicator which either shows “open” or “closed”, as shown in Figure 11. [20, p. 67-72]

Figure 11 - Limit switch for automated ball valve [21]

2.8. ESD Safety Requirements

Barrier management means to establish and maintain barriers to prevent an undesirable event from occurring or by limiting the consequences should an undesirable event occur. This includes the processes, systems, solutions and measures that are in place to ensure the necessary risk reduction through the implementation of follow-up barriers. [6, p. 19]

In barrier management there are a few systems in place to ensure the safety and integrity of the overall system. The main system controlling all other safety functions is the SIS. This is a digital system controlling the ESD/PSD systems and Safety and Automation System (SAS). Within the ESD/PSD system there is a sub-system called Safety Instrumented Function (SIF). [6, p. 18-19]

2.8.1. Safety Instrumented System

A SIS is an automated system that acts to keep a plant in a safe state. Additionally, it can also return the plant to a safe state, should there be abnormal conditions present. The SIS may take a single action or multiple actions to achieve the desirable state, and to protect the plant from hazards. [22]

In most situations, safety is achieved by using a combination of SIS (e.g. ESD, F&G and PSD) and other risk reducing measures. The latter may include technical measures based on other technology than SIS such as pressure relief valves, passive fire protection, drain system, extra wall thickness and distance. [6, p. 18]

The SIS is designed to uphold certain SIL levels depending on the risk associated with the hazard. The higher the SIL, the higher likelihood of redundancy in the system. For example, an ESV has two solenoid valves, one for ESD and one for PSD. This to ensure operability of the valve. [22]

2.8.2. Safety Instrumented Function

A SIF is a control loop in a process or machine which aims to maintain the safety of the process or machine. [23] The risk reduction achieved by a SIF shall include all aspects of the barrier, where the SIF may only be involved in some parts of the barrier. For example, the reliability of the initiating element (e.g. push button) and the reliability of the final element (e.g. a valve) need to be known as well as the reliability of the SIF, to determine the reliability of the barrier. [6, p. 19] The performance of the SIF depends on several factors and is measured by the SIL. SIL is further discussed in Ch. 2.9. [23]

From a technical perspective, the SIF is divided into subsystems as shown in Figure 12.

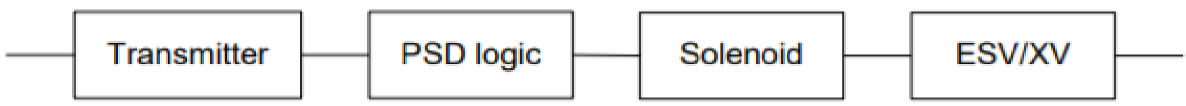

Figure 12 - ESD sub-system: Transmitter/sensor, logic solver and final element (solenoid, actuator and valve) [6, p. 78]

The transmitter/sensor monitors the operational characteristics of the process system in terms of e.g. pressure, flow or temperature and sends a corresponding signal to the logic solver.

The logic solver interprets the signal received from the transmitter and compares it to predefined acceptance criteria. If the information deviates from the criteria, the logic solver will demand an action from the final element to mitigate the deviation in the process. It is common to use a dual logic solver in an ESD system, due to reliability and SIL-requirements.

The final element is the valve, including its connected actuator unit and local control panel (solenoid). The purpose of the final element is to perform the safety function required by stopping or sectionalizing the process. [24, p. 10]

2.9. SIL

Both IEC61508 and IEC61511 recommend a risk-based approach for setting the SIF performance levels by assigning a SIL. For the Norwegian oil and gas industry, it is important to match this principle with the current methods for hazard identification and risk assessment, which includes, but are not limited to, models and system insight that have been developed over several decades. [6, p. 8]

All safety-related systems are assigned a SIL target. A SIL is a representation of how well the system function. There are 4 SIL levels, where 4 is the strictest and 1 is the lowest. The SIL level is set by looking at the average probability of a system failure on demand (PFD). See Figure 13 below. [25]

Safety Integrity Level	Demand Mode of Operation (average probability of failure to perform its design function on demand - PFD)	Continuous / High Demand Mode of Operation (probability of a dangerous failure per hour)
4	$\geq 10^{-5}$ to $< 10^{-4}$	$\geq 10^{-9}$ to $< 10^{-8}$
3	$\geq 10^{-4}$ to $< 10^{-3}$	$\geq 10^{-8}$ to $< 10^{-7}$
2	$\geq 10^{-3}$ to $< 10^{-2}$	$\geq 10^{-7}$ to $< 10^{-6}$
1	$\geq 10^{-2}$ to $< 10^{-1}$	$\geq 10^{-6}$ to $< 10^{-5}$

Figure 13 - SIL level for SIFs [6, p. 32]

HSE management within the scope of IEC61508 and IEC61511 constitutes that all activities necessary to ensure that the SIL requirements are identified, designed and maintained during the entire lifecycle of the systems. These activities are referred to as management of functional safety. [6, p. 8]

2.9.1. Dangerous Undetected and Dangerous Detected Failures

Regarding SIL and PFD, there are two types of failures, the dangerous undetected (DU) failure and dangerous detected (DD) failure. A DD failure is detected by visual inspection or sensors mounted on the valve. A DU failure on the other hand, is not detected automatically, but are usually revealed during leak or function testing or during operation of the valve. Should the DU failure be severe enough it can compromise the safety function of the valve. SIL states the number of DU failures allowed on a piece of equipment. The more failures are detected, the better for the safety system. [26, p. 30]

2.10. Failure Mode Analysis

The analysis in Ch. 4.1 is a variation of a Failure Modes and Effects Analysis (FMEA) where the focus is on the symptoms displayed by the failure modes instead of the effects the failure modes has on the rest of the system. The analysis is therefore named a Failure Mode and Symptom Analysis (FMSA). To date, FMSA is not an established analysis in the industry, but more a variety of a FMEA where the main construction of the analysis is very similar to a FMEA. An introduction to how a FMEA works is therefore given in Ch. 2.10.1.

2.10.1. FMEA

A FMEA is a simple method for analyzing and detecting possible faults and predict the effect of the fault in components or sub-systems. The method is inductive, meaning the basis of the method is to look at each system component and explore what will happen if the component fails. It is important to note that only one component at the time is considered, all other components are considered to work perfectly. FMEA is therefore not suited to detect critical combinations of failures.

The FEMA’s strength is that it gives a systematic overview of potential failures in the system, and therefore forces the constructor to assess the reliability of the system. However, it has some weaknesses: [27, p. 89-93]

- The attention of the FMEA will be mostly on mechanical failures, while failures caused by humans is easily overlooked
- The FMEA can give a poor analysis of systems with a lot of redundancy. In such systems it is not interesting to analyze specific failures, since they do not affect the function of the system
- All component failures are analyzed and documented, also the faults of no or little consequence. This makes an FMEA very time consuming to perform

2.11. Testing

The SCV's are tested regularly to determine the condition and performance of the valve, actuator and local control unit. The test frequency depends on the SCV's function, criticality, system affiliation and related standards. This section introduces the most important terms associated with testing of SCV's.

2.11.1. Travel Time

The travel time is the time used from valve signal initiation to confirmation of the associated position feedback from the valve. For example, the time a fail-close valve use from open to closed position, including the initiation signal through instrumentation and feedback from the limit switches/position indicators.

2.11.2. Safety Critical Time

The safety critical time is the maximum time a safety critical element (SCE) can use to perform its intended safety function. The whole process and all SCE's are considered when calculating the safety critical time.

2.11.3. Function Test

The purpose of a function test is to verify if the valve travels to its fail-safe position within the safety critical time. This includes testing the whole SIS from signal initiation, through the logic solver and receiving feedback that ensures the safe position of the final element. There are two ways to completely or partially test the function of a valve, with a Full Stroke Test (FST) or a Partial Stroke Test (PST).

A FST includes stroking the valve from a fully open to a fully closed position (if fail-close), and the opposite for a fail-open SCV. This implies either testing of the ESD or PSD function, depending on which solenoids and logic solvers are used. In common practice, this is often referred to as ESD/PSD-function testing. A FST may require a planned shutdown, depending on the valve's function, placement and if the process flow can go through a bypass-line during testing.

A frequent FST is not always desirable, due to production loss in the event of a required shutdown. Additionally, too much full stroking will cause unnecessary wear to the valve. A PST may therefore be a supplement and function indication, because it normally does not require a process shutdown. When conducting a PST for a fail-close SCV, the valve typically travels from a 100% open position to 80-90% open position. This provides some diagnostic coverage for the SCV, but should not completely replace a FST. The most important limitations of a PST are: [28, p. 16-23]

- Full travel and closure of the valve/actuator is not demonstrated
- The travel time for a full stroke is not covered
- The seat is not tested against the blocking element in a closed position
- The movement of the seats may be limited compared to a FST
- Limited detection of internal valve degradations

Nevertheless, PST provides some SCV movement confirmation, included solenoids, and it can provide earlier detection of some valve degradation symptoms. Additionally, it can prevent sticking of valve, actuator or solenoid, because of more regular use and movement.

2.11.4. Internal Leak Testing

Internal leak testing is conducted to demonstrate the valve's internal leakage rate. SCV's have leakage requirements dependent on the design standard and system affiliation. This represent the leakage past the final element when a barrier or shutdown is needed. A traditional internal leak test is conducted by closing the valve, pressurizing one side of the valve and monitor the leakage rate on the opposite valve side, during a given time. Dependent on valve and seat design, the leak test can be performed both on the upstream and downstream side. In some procedures, the leakage can also be monitored in the valve cavity, when pressurizing one or both valve sides. The test duration and acceptance criteria are dependent on the associated test standard, valve design, valve size, valve pressure class and seat type. Examples of such standards are ISO 5208, ANSI B16.104/FCI 70-2, API 598 and MSS SP-61. [29]

2.11.5. Conditions Before Testing

To detect the actual condition of the valve, some parameters must be set as a basis before conducting the testing. Examples of such parameters for a function test may be:

- The valve should not be cleaned or lubricated before the test
- The valve should be in the normal position prior to testing
- The valve should not be stroked prior to the actual monitored test
- Determine which solenoids are going to be tested. For example, if the ESD function is tested, a temporary blockage in the logic of the PSD solenoid needs to be established

These are just some examples of relevant parameters. The overall intention of a test is to render the valve's functional state as realistic as possible, without affecting the result with any error sources.

2.11.6. Failure Definitions

Failure definitions must be established prior to the test, dependent on SIS design and relevant valve standards. This shows if the test results are approved according to relevant requirements or not. Examples of failure definitions for a functional test may be:

- The valve does not travel to its fail-safe position
- The valve strokes too unevenly
- The travel time towards the fail-safe position is higher than the safety critical time
- The ESD or PSD solenoid is not activated

2.12. Cost Saving Estimate

In any industry, the potential for increased revenue and profit is always considered. In the oil and gas industry the revenue per day is dictated by the production and oil price and can be calculated by the following equation:

$$Loss\ of\ revenue\left[\frac{USD}{day}\right] = production\left[\frac{bbl}{day}\right] \cdot oil\ price\ \left[\frac{USD}{bbl}\right]$$

The loss of revenue per day gives an indication of the potential related to decreased production downtime. To gain a good perspective of potential savings, the revenue per hour is a good indication, which can be calculated as follows:

$$Revenue\ per\ hour\left[\frac{USD}{hour}\right] = \frac{production\left[\frac{bbl}{day}\right]}{24\left[\frac{hour}{day}\right]} \cdot\ oil\ price\ \left[\frac{USD}{bbl}\right]$$

3. Data Collection

This chapter will describe the current monitoring and planned maintenance of the SCV's topside on the Johan Sverdrup field. An overall description of the ESD system and SCV's are given in the first section. There are several performance requirements related to the ESD system, which will be explored in Ch. 3.2. The current maintenance- and condition monitoring strategy is presented in this Ch. 3.3.

3.1. SCV Testing and Inspection at Johan Sverdrup

The SCV's on the NCS is regularly tested and inspected regarding function and leakage. This section will describe the current routines for testing of the ESD system which is planned at the Johan Sverdrup installation.

3.1.1. The ESD System at Johan Sverdrup

The purpose of the ESD is to prevent escalation of abnormal conditions into a major hazardous event or accident and limit the duration and reach if these types of events should occur. Emergency depressurization and ignition source control is handled by the ESD system.

The ESD system at Johan Sverdrup is directly connected to these systems:

- System 43 – Flare
- System 70 – Fire and gas detection
- System 74 – Process shutdown
- System 77 – Heating, ventilation and air conditioning
- System 80 – Main power
- System 84 – Emergency power generation and distribution
- System 86 – Telecommunication
- System 87 – Automation

The ESD system will perform automatic and manual functions to bring the installation to a predefined safe state. If an automatic initiation fails, the shutdown function or electrical isolation can be manually initiated by a push button at site. Both a manual initiation at site and an automatic initiation will lead to a safe state of the process.

Another important feature of the ESD system is the redundant configuration. Due to the redundancy it is possible to perform maintenance on the ESD system without interrupting operations. The exception is testing of the valves connected to the ESD system. Some of the valves require shutdown of the plant to perform testing and maintenance.

The ESD and PSD levels is organized in a hierarchy, with ESD 0 at the top. ESD 0 is triggered in the event of an Abandon Platform Situation (APS). This can be triggered on a single platform or on all the installations. The purpose of the hierarchy is that if a shutdown is triggered, all shutdown levels below it in the hierarchy will also be triggered. There are two levels of two levels of ESD, ESD 1 and ESD 2, while there are several levels of PSD. So shutdowns are ranked in the following order: [30, p. 18-19]

1. APS
2. ESD 1
3. ESD 2
4. PSD

An example of how the hierarchy looks like is shown in Figure 14 below.

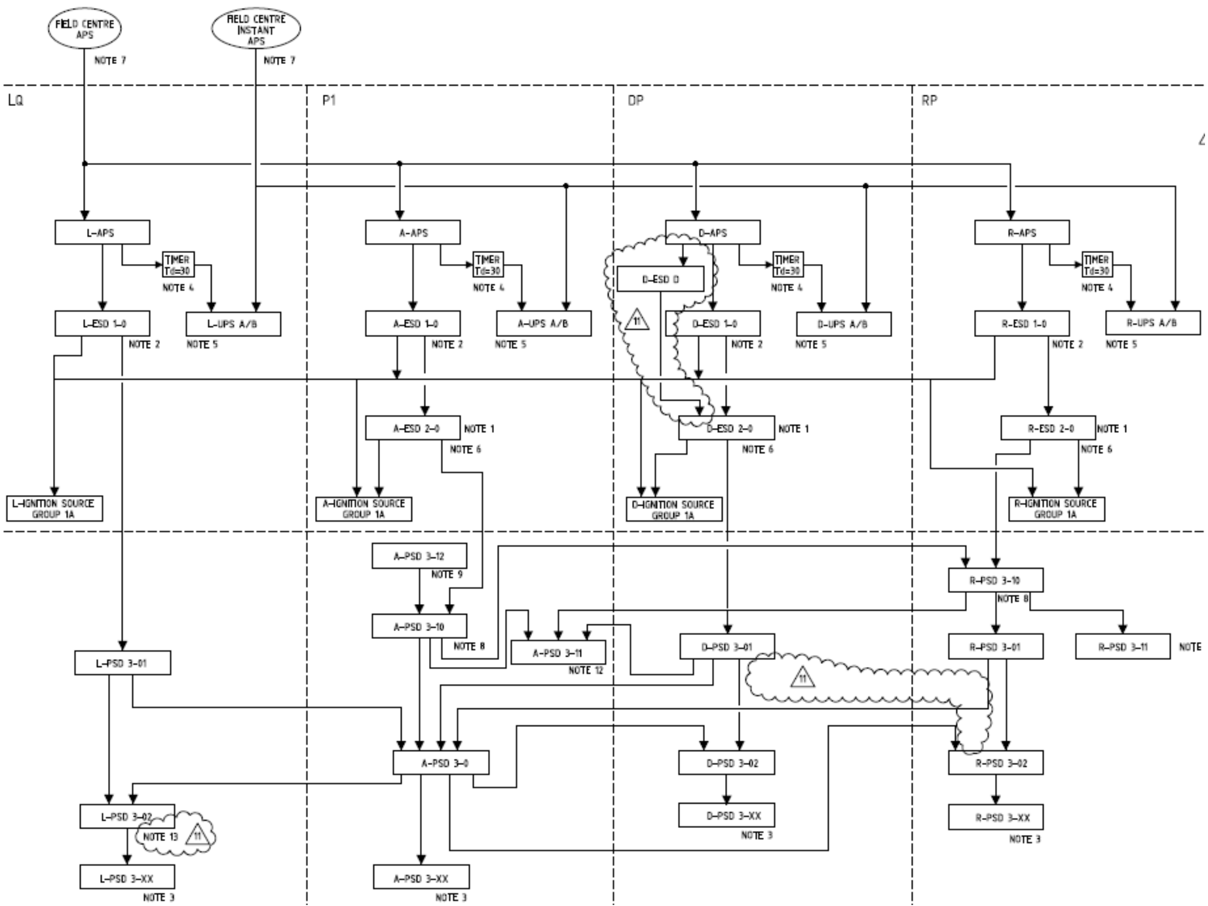

Figure 14 - ESD hierarchy [30]

It is important to note that each of the facilities has its own PSD hierarchy, while the ESD is connected to all. Thus, there might be a process shutdown on one of the platforms, and the others will be unaffected. Should an ESD be triggered on one of the platforms, it will also shut down the others.

The ESV's on the Johan Sverdrup field are mainly ball valves, either floating or trunnion. In addition, pneumatic actuators with a fail close function is almost exclusively used. XSV's are also safety critical valves like the ESV's. However, an XSV is not an emergency valve, and therefore not as critical as an ESV. The ESV's are equipped with two solenoid valves, one for ESD and one for PSD. This means that an ESV can be operated by a low-level PSD, even though it is not an emergency shutdown. This is where the XSV's and ESV's differentiate. The XSV's only have one PSD solenoid valve.

3.2. Performance Requirements

The SCV's at Johan Sverdrup are assigned performance requirements to ensure that they function as intended on demand. Relevant documents like guidelines, technical requirements and standards are established throughout the industry, in addition to internal Equinor documents, to acquire the right safety level at the installation. In the short term, this means to establish a preventive maintenance program, function testing, failure reporting and if necessary; corrective maintenance. In the long term, the failure data from the failure report are reviewed and classified, qualitative and quantitative analysis of the data are conducted, and improvement actions and changes are implemented.

3.2.1. Standards, Guidelines and Technical Requirements

PSAN has established the basis for regulations and laws, regarding all oil and gas activities on the NCS. These regulations specify that all safety functions should have performance requirements. Associated with SCV's, PSAN's most relevant regulations are Management Regulations - Ch.1 §5, Facilities Regulations Ch.2 and Activities Regulations – Ch.4-6 §26, Ch.9 §47. [30, p. 7-13]

The main requirements and regulations for all SIF's in the industry are IEC 61508 and IEC 61511. These standards are made by the International Electrotechnical Commissioning, and describe requirements connected to safety-related systems. The IEC 61508 is the general standard for functional safety, while the IEC 61511 revolves the process control industry. IEC 61508 are normally followed by equipment suppliers and manufacturers, while IEC 61511 are followed by SIS users and designers. [4, 5]

Associated with these standards, PSAN is referring to the document "Norwegian Oil and Gas Application of IEC 61508 and IEC 61511 in the Norwegian Petroleum Industry". This is a guideline (NOG070), which is intended to help operators and other stakeholders to use and follow the mentioned IEC-standards. In practice, these IEC-standards are implemented by following this guideline, in addition to the relevant technical requirements. [6]

Equinor also has internal technical requirements and guidelines. Some of these documents are intended for specific installations, while others are applicable for all Equinor installations at the NCS. As part of the SIS, the SCV's are governed by test procedures and exact requirements related to their intended function. Equinor technical requirements and guidelines refer to the mentioned IEC standards and includes testing of SIS, safety critical failures, SCE reliability targets, SIL calculations and DU failure rates. [30, p. 7-13]

3.2.2. Safety Requirement Specification

The Safety Requirements Specification (SRS) contains information about planning and operating the SIF's at an installation. It is initially derived from the allocation of SIFs and from those requirements identified during safety planning. The purpose is to provide a basis for system design, and the SRS shall be further developed and maintained through all lifecycle phases of the SIS.

The SRS is the main document regarding SIS related requirements and shall include reliability/PFD targets, as well as assumed demand rates and spurious trip rates. It shall focus on the most critical requirements (ref. IEC 61511-1, cl. 10.3.2) and should provide such information in a short and concise manner. This includes the required proof test frequencies, which again directly affects the planned operation and maintenance of the SCV's at Johan Sverdrup. [6, p. 38]

In the operational phase of Johan Sverdrup, the SRS specifies the four following activities as part of a continuous SIS working process:

- Data collection and analysis
- Performance testing
- Operation, maintenance and repair
- Update failure data and test intervals

All these four activities are directly connected to the planned operation and maintenance of the SCV's. With the sufficient development and implementation of new CM technology, all these activities may be affected. [6, p. 175-177]

3.2.3. Reliability Targets and Test Intervals

SCV’s are typically classified as SIL 2 SIF’s, with the associated PFD target of 0.014. This includes the valve, actuator and control panel, without the ESD node [26, p. 16]. Both the SCV’s and other SIF’s are identified and controlled against the relevant global requirements and specified further in internal Equinor functional safety management plans. These management plans refer to the mentioned documents like IEC 61508, IEC 61511, PSAN (NOG070) and other internal Equinor (multi-field) technical requirements.

An example of the practical significance of the reliability targets, are the test intervals which all SCV’s are assigned. These intervals depend on the results from the SRS and SIL-studies but are typically presented with 12 months intervals for SCV’s (if sufficient). The test interval is an important part of the preventive maintenance and should consider the manufacturers recommendations and experienced practice in Equinor. Relevant documents also require updating the intervals gradually if necessary, after a given time of production and experience at the installation. This is relevant when collected failure data can justify a change of the test interval. It is therefore difficult to update any intervals at Johan Sverdrup at this date, since the installation has not started production. [31, p. 6-7]

3.2.4. Valve Criticality

In the detailed engineering phase of the Johan Sverdrup project, a SCV study was conducted by SafeTec, an ABS Group company. Equinor requirements states that SCV’s found particularly critical in the case of the consequences of an internal leakage, should be governed by a leak testing program. The safety criticality is considered by the consequences if a SCV fails to perform its safety function. This includes the consequences of a leakage between process segments and fire escalation between areas. The valve criticality is divided into four categories, with their associated description, consequence and testing requirement: [32, p. 20-21]

Table 2 - Valve criticality [32, p. 21]

Valve Type	Valve Criticality	Valve Description/Function	Potential Consequence	Leak Testing Requirement
ESV/XSV	1A	Isolation of gas or liquid hydrocarbon import/export riser and pipeline.	Potentially long lasting/large leaks with severe consequences for personnel and Main Safety Functions. The exception is stabilized oil with measures to prevent crude flow and limited static head.	Shall be leak tested, unless the medium is stabilized oil with conditions as specified to the left.
	1B/C	Valve in liquid (1B) or gas (1C) service as part of area sectionalizing, separating: - Process segments not simultaneously depressurized. - Storage areas that may result in fire loads exceeding dimensioning fire criteria of the area. - Process segments that may, given a leak, result in fire loads exceeding dimensioning fire criteria.	Fire loads exceeding the dimensioning fire criteria in the area.	Shall be leak tested, unless it can be documented that maximum internal leak rate will not be safety critical.
	1D	The valve provides isolation of process units/equipment.	Leakage will result in a major process accidental event – e.g. pressurization and rupture of process vessel, escape of toxic liquid or gasses.	Shall be leak tested if leak occurrence will result in risk that are not tolerable.

3.3. Current Condition Monitoring

The chosen CM system for the SCV's at Johan Sverdrup is the brand ValveWatch. This system is developed and delivered by MRC Global Norway. They supply services and products connected to instrumentation, piping and valves in the oil and gas industry.

3.3.1. ValveWatch

When conducting the detailed engineering phase on the Johan Sverdrup project, the ValveWatch system was decided to be installed on the most important valves on the installation. ValveWatch is a CM system designed to detect faults and wear on valves.

Dependent on the sensor configuration and use utilization, it can both increase CM-, valve testing- and corrective maintenance efficiency. As an independent online monitoring system, it provides real-time data which can be used to identify potential valve or actuator problems before reduced performance or disastrous errors occur. The purpose of ValveWatch is to determine accurate sealing or functional integrity of a SCV from a local or external position. It gives a qualitative evaluation of the dynamic SCV performance, using an acoustic sensor or pressure transmitters (dynamic) upstream, in the cavity and/or downstream of the SCV. Static sensors like a strain gauge and actuator pressure sensor can also be used to monitor the functional performance when the valve is operated. [7]

ValveWatch has been installed on 272 SCV's at the Johan Sverdrup platforms. 267 of these have an actuator pressure sensor and the five most critical valves have an actuator pressure sensor, yoke/pedestal strain gauge and two dynamic leak sensors. The selected ValveWatch configurations will increase the CM possibilities, especially for the five most critical SCV's.

3.3.2. Current Condition Monitoring Strategy

The possibilities and utilization of ValveWatch as a CM tool at Johan Sverdrup is not planned into detail by Equinor yet. It will be used as a troubleshooting tool and potentially more condition overview when the valves are operated.

All SCV's on Johan Sverdrup has an actuator pressure sensor installed which can be used to see the development of the condition of the SCV, by comparing the actuator pressure curve over time. This can be done automatically when the SCV is operated or initiated manually when it is possible to operate the SCV without affecting the production. The five most critical SCV's has a lot more possibilities regarding troubleshooting and CM, due to the extended ValveWatch system. They are installed with an actuator pressure sensor, yoke/pedestal strain gauge and two dynamic leak sensors. These sensors combined will assist in monitoring the condition of the valve trim and leak rate when the valve is operated.

3.4. Testing Activities

Testing and inspections are the planned activities of SCV's at Johan Sverdrup in order to maintain and verify the intended SIF. The intention of all the tests is to indicate and identify relevant failure mechanisms and failure modes.

The SCV's at Johan Sverdrup will be assigned standardized Equinor maintenance activities, including testing and inspections. Dependent on each valve's criticality for safety and production, they are assigned one or several of the following maintenance activities:

- Function test – Actuated ESD valve
- Function test – Actuated PSD valve
- Leak test – Actuated ESD valve
- Leak test – Actuated PSD valve

The tests are considered separately because the consequences of a failure in each test are significantly different and they might not be performed at the same time. These maintenance activities are standardized procedures in the Equinor operation and maintenance plan, and most are planned to be conducted with a 12 months interval.

Function testing is used to verify that SCV's can perform their intended safety function. By conducting function testing as preventive maintenance, an indication of the condition of the valve, actuator and control unit should be attained. Especially the solenoid valves are critical, due to the tendency of getting stuck if they are not operated regularly. For ESV's which both have an ESD and a PSD solenoid, the PSD solenoid is used more often for process shutdowns, while the ESD solenoid is only initiated for emergency shutdowns. It is therefore critical that the ESD solenoid works as intended on demand. A function test, also called a valve stroke test, is therefore intended to verify that a SCV responds when an emergency shutdown is necessary. At the same time, it is not desired to perform a function test more often than necessary, due to equipment wear and potential production downtime when operating a SCV.

Dependent on a SCV's system affiliation and placement, a partially or complete production shutdown may be necessary when conducting a function test. An alternative supplement is therefore a PST. It is then verified that the SCV is free to travel from approximately 100-80%, by activating the solenoids separately, without causing an unplanned shutdown. [33, p. 3-6]

3.4.1. Full Stroke Test

The typical requirements when conducting a FST, is that the valve obtains its safe state within a given time, i.e. fully closing for a fail-close valve and fully opening for a fail-open valve. The time requirements are normally given in the installation specific requirements. There are two different requirements given for each valve size. One requirement indicates if the valve is "degraded" and the other requirement indicate the "safety critical" time for the SIF. If the test result time is above the "degraded" time, troubleshooting and possibly corrective maintenance is required. The "safety critical" time indicates the maximum travel time before a SCV does not maintain its SIF in the SIS.

As a confirmation of the valve position and test result, the limit switch or a visual field inspection at site should also be included in the FST. This is intended as evidence of the actual position of the valve. [31, p. 13]

3.4.2. Partial Stroke Test

PST has some possibilities as preventive maintenance and condition indication, even if it is not a complete test. Because of the limited travel, the PST will not cover all failure modes and mechanism compared to an FST. It is therefore important to document properly which failure modes and mechanism are covered when conducting a PST. As a general guideline, a PST can extend the required test interval for an FST by the maximum of one year. The criteria for such an extension are that the initial break away force for the valve travel start is lower than any of the required force during the whole valve stroke. Additionally, anything preventing a full stroke should be monitored and cleared, such as wax, scaling or other foreign objects in the valve bore. [31, p. 24]

Equinor has not planned in detail how PST shall be a part of the maintenance and testing activities at Johan Sverdrup. By developing a strategy to use a combination of ValveWatch and PST, more failure modes and mechanisms can be discovered.

3.4.3. Leak Test

SCV's that are critical to the production have requirements regarding internal leakage through the valve in a closed position. The reason for this, is the potential consequences if a significant internal leakage should occur in an emergency. Such a leakage could feed a fire or hydrocarbon leakage downstream of the valve. Leak testing will be executed with the maximum operating differential pressure in the current system, to illustrate a realistic operational situation. [31, p. 13]

The annual leak test will be executed by attaching a pressure gauge at the valve cavity or downstream the valve, and then monitoring a possibly pressure build-up during a given time. This requires at least one operator to attach and monitor the pressure gauge, one operator to pressurize the valve or cavity and one operator to monitor the process status from Central Control Room (CCR). A leak test like this is estimated to last for 1 hour for each valve, not including the time for preparation, demobilization and result analysis. It is therefore a potential to improve the test efficiency. Leakage requirements depend on the valve and seat design and are either given in the specific installation documentation or in general according to test standards. Equinor has proposed two different test methods regarding leakage testing:

A1 - Leakage Across the Valve

The A1 test is a leak test where the downstream pressure is measured and compared to the upstream pressure at a given time interval. By measuring the downstream pressure change in a known volume, the leakage rate can be calculated across the valve in a closed position.

A2 - Leakage to Valve Cavity

The A2 test is a leak test where the cavity pressure is measured and compared to the upstream pressure in a given time interval. The cavity volume is known and by first reducing the cavity pressure, the pressure will increase and therefor the leakage can be measured. [34, p. 6-8]

3.4.4. Alternative Test Methods

Alternative test methods for both function and leak testing might be implemented. A specific evaluation needs to be conducted to verify that the relevant failure mechanisms and modes are controlled with the proposed method.

An example of this can be the use of sensors and systems such as ValveWatch, when conducting testing. This can form a basis to get an overview of the SCV condition. New test method suggestions are normally evaluated conservatively and needs to be statistically and practically documented, considering coverage and reliability [31, p. 13]. The possibilities and evaluation of ValveWatch as part of the planned SCV testing will be considered further in Chapter 4.

3.5. Potential Savings Analysis Data

Data collection for the potential savings estimate is very simplistic but will give an indication of the potential cost savings. At peak production Johan Sverdrup will produce 660,000 bbl/day. For the potential lifetime-savings, a lower production will be assumed to accommodate a lower production in the early stages of operation, and with an increasing production time the actual oil production will decrease. An average oil production is there for assumed to be 450,000bbl/day when looking at 50 years of production. The oil price is constantly fluctuating. A fixed oil price of 70 USD/bbl will therefore be assumed for simplicity.

The data in the potential savings analysis is mostly based on assumptions. They should therefore be handled with caution and will only give an indication of the potential savings related to a reduction in downtime.

3.6. Secondary Data from Equinor

Data and documentation provided by Equinor is based on current company and industry standards. Guidelines, technical requirements and SRS are all in daily use by the employees at Equinor. These documents are the foundation for all work done in engineering and planning. The documentation is developed based on industry standards set by the Norwegian government, international industry standards in addition to experience gained by Equinor since the company was founded. This makes the data very reliable and up to date with the newest regulations and industry standards.

4. Data Analysis

The purpose of this chapter is to provide an analysis to be able to match failure modes, severity of failure and ValveWatch sensors. The analysis is a modified FMEA, hereby called FMSA, which lists failure modes, mechanisms and degradations, severity (criticality), likelihood of occurrence and sensors delivered by ValveWatch. This FMSA will be used to:

- Determine which sensors can detect failures during normal operation as a CM program
- Determine how the sensors can aid in the yearly testing of the valve
- Evaluate which sensors will be beneficial to install

In total, this aims to increase the overall safety, reliability, technical integrity and cost efficiency for the operation and maintenance strategy for all topside SCV's at Johan Sverdrup.

4.1. Failure Modes and Symptoms

ValveWatch offers a wide range of sensors to monitor and detect failures on valves. The sensors provide an automatic update on the condition and performance of the valve and actuator. This enables the operator to correct potential failures before they occur. [35]

The analysis presented in this thesis was developed to be able to match the most likely failures to occur on an automated valve and what failures the sensors can detect. By matching the failures and sensors the analysis shows which type of failures each sensor can detect and it shows which failures might not be detected by a sensor.

The failures listed in the FMSA, Table 6, is found in ISA-TR96.05.01-2017. ISA is an organization working together with many different companies, creating an expert panel, to make the instrumentation field more uniform, and give a general guideline on the subject. The failures listed in the FMSA is the failures which happens in 95,2% of the times an automated valve fails, i.e. the expected and known root causes. It is important to note that ISA does not differentiate between a functional failure and a degradation. Therefore, the failures listed below the ISA failure are a combination of a failure mode and a failure mechanism. For simplicity the ISA failure/degradation is hereby called a failure, and the failure modes and mechanisms listed below the main failure, are modes and mechanisms that can lead to the main failure. These failures are hereby named sub-failures. [28, p. 27-29]

The FMSA is divided into several columns. The ISO failure mode is to describe which category the failure is in and is chosen to be the same as for failure modes on valves in SAP. They are abbreviated as follows in Table 3 below:

Table 3 - SAP failure mode codes

BRD	Breakdown	FTC	Failure to close on demand
DEX	Defective EX protection	FTO	Failure to open on demand
DOP	Delayed operation	INL	Internal leakage
ELP	External leakage - Process	LCP	Leakage in closed position
ELU	External leakage - Utility	STD	Structural deficiency

In the next column the failures, with accompanying sub-failures, are listed. The failures are listed as a combination of failure modes and failure mechanisms, i.e. the sub-failures. The next column indicates the location of the failure and is abbreviated as follows in Table 4.

Table 4 - Abbreviations for failure location

A	Actuator	V	Valve
P	Positioner	T	Tubing
R	Filter regulator	F	Fittings
S	Solenoid	B	Volume Booster

The severity of a failure is ranked from 1 to 4 in a hierarchy. The hierarchy is given in Table 5:

Table 5 - Severity of failure

1	Minor disturbance during operation of ESV/XSV
2	Moderate disturbance during operation of ESV/XSV
3	Major disturbance, causes unintended shutdown
4	Catastrophic, ESV/XSV does not function as intended on demand

A category 3 failure will cause the SCV to fail, triggering the fail-safe function of the valve. Thus, keeping the safety function of the valve intact, but the failure of the valve may lead to a process shutdown and loss of production. In a severity 4 failure, the SCV will not function as intended on demand and the fail-safe function is not working, which in turn means a loss of the safety barrier. The sub-failures dictate the overall severity of the failure. The highest severity sub-failure will automatically set the same severity for the failure.

The likelihood of occurrence shows the likelihood of a failure being that specific failure. This must not be confused with failure rate. The likelihood of occurrence was developed for each failure based on experience from many different operating companies with different process facilities. [28, p. 25]

The rest of the columns show how each of the sensors and monitoring techniques can detect each sub-failure. It is important to note that some of the sensors monitors the SCV continuously, while some monitors when the SCV is operated. How each of the sensors detect failures is discussed in Ch. 4.2. The sensors are given a score from 0 to 2 on how well they can detect the failure. If a sensor is scored as 0, it cannot detect the sub-failure. A sensor with the score 1, can detect that something is wrong (to a certain extent), but not pinpoint the exact fault. For simplicity, it is weighted as 50% coverage of the sub-failure. If a sensor is scored as a 2, it can detect the sub-failure 100%. These scores are combined to give an indication of the coverage the sensor has of the failure. At the bottom of the analysis, the coverage degree is calculated for all failures. It is important to note that this percentage indication is meant as a guide, not as a decision tool.

Table 6 - FMSA with failures, sub-failures and sensors

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
1	DOP	**Partial or intermittent sticking of hydraulic or pneumatic system components such as solenoids, pilots, speed controller, etc due to moisture, debris or alignment**	P, R, S	**2**	**20,0 %**	40,0 %	15,0 %	20,0 %	50,0 %	30,0 %	0,0 %	30,0 %	5,0 %	5,0 %	5,0 %	70,0 %	80,0 %
	DOP	Feedback assembly misalignment/ damage	P	2		2	0	1	0	0	0	0	0	0	0	1	2
	DOP	I/P malfunction	P	2		0	0	0	1	0	0	1	0	0	0	1	2
	DOP	Relay malfunction	P	2		0	0	0	1	0	0	1	0	0	0	1	2
	DOP	Insufficient air supply	P	2		1	1	1	1	1	0	0	0	0	0	2	2
	DOP	Poor response (tuning problem)	P	2		0	0	0	1	0	0	0	0	0	0	2	2
	DOP	Wrong adjusted set pressure	R	2		2	1	1	2	1	0	1	0	0	0	2	2
	DOP	Degraded filter unit	R	2		0	1	1	1	1	0	1	1	1	1	1	1
	DOP	Stiction, reduced performance	S	2		0	0	0	1	1	0	0	0	0	0	2	1
	DOP	Blocked exhaust	S	2		1	0	0	1	2	0	1	0	0	0	1	1
	DOP	External leakage	P	1		2	0	0	1	0	0	1	0	0	0	1	1
2	DOP, STD	**Binding, galling or other degradation of valve seats or related flow control trim that only restricts or resists valve movement**	V	**2**	**18,0 %**	20,0 %	10,0 %	20,0 %	70,0 %	0,0 %	0,0 %	80,0 %	40,0 %	40,0 %	0,0 %	80,0 %	80,0 %
	STD	Internal trim damage	V	2		0	0	0	1	0	0	2	2	2	0	1	1
	STD	Internal trim corrosion/erosion	V	2		0	0	0	0	0	0	1	1	1	0	1	1
	STD	Internal trim misalignement , galling	V	2		0	0	0	2	0	0	1	1	1	0	2	2
	DOP	High friction, scaling etc.	V	2		0	1	1	2	0	0	2	0	0	0	2	2
	DOP	Stick-slip effect	V	2		2	0	1	2	0	0	2	0	0	0	2	2

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
3	ELU, STD, INL, DOP	**Actuator seal degradation caused by compression, wear or looseness that reduces the pressure available to actuate the valve.**	A	**2**	**16,0 %**	30,0 %	10,0 %	10,0 %	70,0 %	0,0 %	0,0 %	60,0 %	0,0 %	10,0 %	0,0 %	90,0 %	70,0 %
	ELU	External leakage	A	2		2	0	0	2	0	0	1	0	1	0	2	1
	STD	Stem damage, scratches or wear	A	2		1	0	0	1	0	0	2	0	0	0	2	1
	INL	Internal leakage	A	2		0	0	0	2	0	0	1	0	0	0	2	2
	STD	Internal corrosion - piston actuator	A	2		0	0	0	1	0	0	1	0	0	0	1	1
	DOP	Internal misalignment, galling	A	2		0	1	1	1	0	0	1	0	0	0	2	2
4	INL, LCP, STD, DOP	**Minor damage to the valve obturator plug, disk or ball caused by system conditions, leakage or debris including build-up of hydrocarbon products.**	V	**2**	**8,0 %**	12,5 %	6,3 %	18,8 %	43,8 %	0,0 %	25,0 %	50,0 %	50,0 %	37,5 %	0,0 %	56,3 %	50,0 %
	INL	Internal leakage valve open	V	2		0	0	0	0	0	2	0	2	0	0	0	0
	LCP	Internal leakage valve closed	V	2		0	0	0	0	0	2	0	2	2	0	1	0
	STD	Internal body corrosion/ erosion	V	2		0	0	0	0	0	0	0	0	0	0	0	0
	STD	Internal trim corrosion/erosion	V	2		0	0	0	0	0	0	1	1	1	0	1	1
	STD	Internal trim misalignment, galling	V	2		0	0	0	2	0	0	1	1	1	0	2	2
	STD	Internal trim damage	V	2		0	0	1	1	0	0	2	2	2	0	1	1
	DOP	High friction, scaling etc.	V	2		0	1	1	2	0	0	2	0	0	0	2	2
	DOP	Stick-slip effect	V	2		2	0	1	2	0	0	2	0	0	0	2	2
5	FTC, FTO	**Complete failure of hydraulic control system components such as solenoids, pilots, speed controller, etc due to moisture, debris or alignment.**	P, R, S	**3**	**6,0 %**	35,0 %	15,0 %	35,0 %	50,0 %	40,0 %	0,0 %	30,0 %	5,0 %	5,0 %	5,0 %	75,0 %	80,0 %
	FTC/FTO	Feedback assembly misalignment/ damage	P	3		2	0	1	0	0	0	0	0	0	0	1	2
	FTC/FTO	I/P malfunction	P	3		0	0	0	1	0	0	1	0	0	0	1	2
	FTC/FTO	Relay malfunction	P	3		0	0	0	1	0	0	1	0	0	0	1	2

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
	FTC/FTO	Insufficient air supply	P	3		1	1	1	1	1	0	0	0	0	0	2	2
	FTO/FTC	Poor calibration	P	3		1	0	1	0	0	0	0	0	0	0	2	2
	FTC/FTO	Wrong adjusted set pressure	R	3		2	0	1	2	1	0	0	0	0	0	2	2
	FTC/DTO	Degraded filter unit	R	3		0	1	1	1	1	0	1	1	1	1	1	1
	FTC/FTO	Stiction, reduced performance	S	3		0	0	1	1	1	0	1	0	0	0	2	1
	FTC/FTO	Stuck	S	3		0	1	1	2	2	0	1	0	0	0	2	1
	FTC/FTO	Blocked exhaust	S	3		1	0	0	1	2	0	1	0	0	0	1	1
6	INL/LCP/ STD/ DOP/FTC /FTO	**Process media leakage through severely damaged seat rings or other flow control trim due to debris, wear or looseness**	V	**4**	**4,0 %**	12,5 %	6,3 %	18,8 %	43,8 %	0,0 %	25,0 %	56,3 %	50,0 %	37,5 %	0,0 %	56,3 %	50,0 %
	INL	Internal leakage valve open	V	4		0	0	0	0	0	2	0	2	0	0	0	0
	LCP	Internal leakage valve closed	V	4		0	0	0	0	0	2	0	2	2	0	1	0
	STD	Internal body corrosion/ erosion	V	3		0	0	0	0	0	0	1	0	0	0	0	0
	STD	Internal trim corrosion/erosion	V	3		0	0	0	0	0	0	1	1	1	0	1	1
	STD	Internal trim misalignment, galling	V	3		0	0	0	2	0	0	1	1	1	0	2	2
	STD	Internal trim damage	V	3		0	0	1	1	0	0	2	2	2	0	1	1
	DOP/FTC /FTO	High friction, scaling etc.	V	4		0	1	1	2	0	0	2	0	0	0	2	2
	DOP/FTC /FTO	Stick-slip effect	V	4		2	0	1	2	0	0	2	0	0	0	2	2
7	INL, LCP, STD, DOP	**Severe damage to the valve obturator plug, disk or ball including scoring caused by system conditions, leakage or debris including build-up of hydrocarbon products**	V	**4**	**3,0 %**	12,5 %	6,3 %	18,8 %	43,8 %	0,0 %	25,0 %	50,0 %	50,0 %	37,5 %	0,0 %	56,3 %	50,0 %
	INL	Internal leakage valve open	V	4		0	0	0	0	0	2	0	2	0	0	0	0
	LCP	Internal leakage valve closed	V	4		0	0	0	0	0	2	0	2	2	0	1	0
	STD	Internal body corrosion/ erosion	V	3		0	0	0	0	0	0	0	0	0	0	0	0
	STD	Internal trim corrosion/erosion	V	3		0	0	0	0	0	0	1	1	1	0	1	1

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
	STD	Internal trim misalignment, galling	V	3		0	0	0	2	0	0	1	1	1	0	2	2
	STD	Internal trim damage	V	3		0	0	1	1	0	0	2	2	2	0	1	1
	DOP	High friction, scaling etc.	V	4		0	1	1	2	0	0	2	0	0	0	2	2
	DOP	Stick-slip effect	V	4		2	0	1	2	0	0	2	0	0	0	2	2
8	ELU, STD, INL, DOP, FTO, FTC	**Complete actuator seal degradation caused by compression, wear or looseness that discharges the pressure available to actuate a valve**	A	**4**	**3,0 %**	30,0 %	0,0 %	0,0 %	70,0 %	0,0 %	0,0 %	50,0 %	0,0 %	10,0 %	0,0 %	90,0 %	70,0 %
	ELU	External leakage	A	3		2	0	0	2	0	0	1	0	1	0	2	1
	STD	Stem damage, scratches or wear	A	4		1	0	0	1	0	0	1	0	0	0	2	1
	INL	Internal leakage	A	3		0	0	0	2	0	0	1	0	0	0	2	2
	STD	Internal corrosion - piston actuator	A	4		0	0	0	1	0	0	1	0	0	0	1	1
	DOP/FTC	Internal misalignment, galling	A	4		0	0	0	1	0	0	1	0	0	0	2	2
9	-	**NA - Degraded HPU pump motor or other HPU control components**	NA	NA	**2,0 %**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	ELP, STD	**Valve packing or other stem sealing degradation due to decompression, wear or looseness**	V	**3**	**2,0 %**	60,0 %	0,0 %	0,0 %	40,0 %	0,0 %	0,0 %	50,0 %	0,0 %	10,0 %	0,0 %	50,0 %	50,0 %
	ELP	External leakage	V	3		2	0	0	0	0	0	0	0	1	0	0	0
	STD	Stem damage, scratches or wear	V	3		1	0	0	1	0	0	1	0	0	0	1	1
	STD	Bent stem	V	3		1	0	0	2	0	0	2	0	0	0	2	2
	STD	Low friction, packing/seals worn out	V	3		0	0	0	1	0	0	2	0	0	0	2	2
	STD	External corrosion	V	2		2	0	0	0	0	0	0	0	0	0	0	0
11	STD, DOP	**Actuator piston slight to moderate misalignment or otherwise damaged**	A	**2**	**2,0 %**	0,0 %	13,8 %	20,6 %	66,3 %	0,0 %	0,0 %	52,5 %	0,0 %	0,0 %	0,0 %	80,6 %	80,0 %
	STD	Internal corrosion - piston actuator	A	2		0	0	0	1	0	0	1	0	0	0	1	1

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
	DOP	Internal misalignment, galling	A	2		0	1	1	1	0	0	1	0	0	0	2	2
	DOP	Wrong engineered / designed actuator	A	2		0	0	0	1	0	0	1	0	0	0	2	2
	STD	Spring damaged or broken	A	2		0	0	1	2	0	0	1	0	0	0	2	2
	DOP	Spring unlinearity / bent spring	A	2		0	1	1	2	0	0	1	0	0	0	2	2
12	STD, DOP	**Valve stem bent or twisted due to excessive force, galled, scored or damaged due to leakage**	V, A, P	**2**	**2,0 %**	40,0 %	20,0 %	30,0 %	60,0 %	0,0 %	0,0 %	40,0 %	0,0 %	0,0 %	0,0 %	90,0 %	80,0 %
	STD	Stem damage, scratches or wear	V	2		1	0	0	1	0	0	1	0	0	0	1	1
	STD	Bent stem	V	2		1	0	0	2	0	0	2	0	0	0	2	2
	DOP	Wrong initial compression	A	2		0	0	0	2	0	0	0	0	0	0	2	2
	DOP	Wrong mechanical connection (wrong travel)	A	2		1	1	2	0	0	0	0	0	0	0	2	1
	DOP	Poor calibration	P	2		1	1	1	1	0	0	1	0	0	0	2	2
13	DOP	**Debris, misalignment or other valve seat or seal degradation affecting smooth operation**	V	**2**	**1,0 %**	50,0 %	0,0 %	50,0 %	100,0 %	0,0 %	0,0 %	100,0 %	0,0 %	0,0 %	0,0 %	100,0 %	100,0 %
	DOP	High friction, scaling etc.	V	2		0	0	1	2	0	0	2	0	0	0	2	2
	DOP	Stick-slip effect	V	2		2	0	1	2	0	0	2	0	0	0	2	2
14	STD, ELP	**Physical damage to valve flange and flange bolts due to corrosion, accidental impacts or stress**	V	**3**	**1,0 %**	100,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	25,0 %	0,0 %	0,0 %	0,0 %
	STD	External corrosion	V	3		2	0	0	0	0	0	0	0	0	0	0	0
	ELP	External leakage	V	3		2	0	0	0	0	0	0	0	1	0	0	0
15	STD, ELP, SOP	**Moderately bent or twisted valve stem due to excessive force, severely galled, scored or damaged due to leakage**	V, A, P	**3**	**1,0 %**	40,0 %	20,0 %	30,0 %	50,0 %	0,0 %	0,0 %	40,0 %	0,0 %	0,0 %	0,0 %	90,0 %	80,0 %
	STD	Stem damage, scratches or wear	V	3		1	0	0	1	0	0	1	0	0	0	1	1
	STD/ELP	Bent stem	V	3		1	0	0	1	0	0	2	0	0	0	2	2
	DOP	Wrong initial compression	A	3		0	0	0	2	0	0	0	0	0	0	2	2

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
	DOP	Wrong mechanical connection (wrong travel)	A	3		1	1	2	0	0	0	0	0	0	0	2	1
	DOP	Poor calibration	P	3		1	1	1	1	0	0	1	0	0	0	2	2
16	DOP, STD, ELU	**Bent, loose or otherwise damaged hydraulic or pneumatic tubing or connectors, includes obstructions caused by moisture or debris but the valve operates**	T/F	**2**	**1,0 %**	100,0 %	0,0 %	0,0 %	25,0 %	0,0 %	0,0 %	25,0 %	0,0 %	0,0 %	0,0 %	25,0 %	25,0 %
	STD	External corrosion	T/F	1		2	0	0	0	0	0	0	0	0	0	0	0
	ELU/DOP	External leakage	T/F	2		2	0	0	1	0	0	1	0	0	0	1	1
17	DOP, STD, ELU	**Corroded, bent or otherwise damaged actuator, cylinder, piston tubes or casing**	A	**2**	**0,8 %**	100,0 %	0,0 %	0,0 %	50,0 %	0,0 %	0,0 %	25,0 %	0,0 %	25,0 %	0,0 %	50,0 %	25,0 %
	STD	External corrosion	A	1		2	0	0	0	0	0	0	0	0	0	0	0
	ELU/DOP	External leakage	A	2		2	0	0	2	0	0	1	0	1	0	2	1
18	FTO, FTC	**Broken or mispositioned electrical interlocks and permissives affecting operation**	P	**3**	**0,8 %**	20,0 %	20,0 %	20,0 %	50,0 %	10,0 %	0,0 %	40,0 %	0,0 %	0,0 %	0,0 %	80,0 %	100,0 %
	FTO/FTC	I/P malfunction	P	3		0	0	0	1	0	0	1	0	0	0	1	2
	FTO/FTC	Relay malfunction	P	3		0	0	0	1	0	0	0	0	0	0	1	2
	FTO/FTC	Insufficient air supply	P	3		1	1	1	1	1	0	1	0	0	0	2	2
	FTO/FTC	Poor response (tuning problem)	P	2		0	0	0	1	0	0	1	0	0	0	2	2
	FTO/FTC	Poor calibration	P	3		1	1	1	1	0	0	1	0	0	0	2	2
19	ELP, STD	**Degraded body gaskets or seals**	V	**2**	**0,8 %**	66,7 %	0,0 %	0,0 %	16,7 %	0,0 %	0,0 %	33,3 %	0,0 %	16,7 %	0,0 %	33,3 %	33,3 %
	STD	External corrosion	V	1		2	0	0	0	0	0	0	0	0	0	0	0
	ELP	External leakage	V	2		2	0	0	0	0	0	0	0	1	0	0	0
	STD	Low friction, packing/seals worn out	V	2		0	0	0	1	0	0	2	0	0	0	2	2

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
20	ELU, DOP, STD	**Filters or regulator flow path degraded due to debris or unable to provide the required hydraulic or pneumatic fluids**	R	**2**	**0,5 %**	75,0 %	25,0 %	37,5 %	50,0 %	37,5 %	0,0 %	25,0 %	25,0 %	25,0 %	25,0 %	50,0 %	50,0 %
	STD	External corrosion	R	1		2	0	0	0	0	0	0	0	0	0	0	0
	ELU	External leakage	R	2		2	0	1	1	1	0	1	1	1	1	1	1
	DOP	Wrong adjusted set pressure	R	2		2	1	1	2	1	0	0	0	0	0	2	2
	DOP	Degraded filter unit	R	2		0	1	1	1	1	0	1	1	1	1	1	1
21	STD, FTC, FTO	**Closure member, obturator, ball, plug or disk blocked, obstructed or otherwise unable to move due to physical damage including scoring caused by system conditions, leakage or debris including build-up of hydrocarbon products**	V	**4**	**0,5 %**	20,0 %	20,0 %	30,0 %	70,0 %	0,0 %	0,0 %	90,0 %	40,0 %	40,0 %	0,0 %	80,0 %	80,0 %
	STD	Internal trim corrosion/erosion	V	4		0	0	0	0	0	0	1	1	1	0	1	1
	STD	Internal trim misalignment, galling	V	4		0	0	0	2	0	0	2	1	1	0	2	2
	STD	Internal trim damage	V	4		0	0	1	1	0	0	2	2	2	0	1	1
	FTC/FTO	High friction, scaling etc.	V	4		0	1	1	2	0	0	2	0	0	0	2	2
	FTC/FTO	Stick-slip effect	V	3		2	1	1	2	0	0	2	0	0	0	2	2
22	ELU, FTO, FTC, STD	**Severely corroded, bent or otherwise damaged actuator cylinder, piston tubes, casing or diaphragm**	A	**3**	**0,5 %**	100,0 %	0,0 %	0,0 %	50,0 %	0,0 %	0,0 %	25,0 %	0,0 %	25,0 %	0,0 %	50,0 %	25,0 %
	STD	External corrosion	A	2		2	0	0	0	0	0	0	0	0	0	0	0
	ELU/FTO/ FTC	External leakage	A	3		2	0	0	2	0	0	1	0	1	0	2	1
23	STD, ELP, DOP, FTC, FTO	**Severely bent or twisted valve stem due to excessive force, severely galled, scored or damage due to leakage**	V, A, P	**4**	**0,5 %**	40,0 %	20,0 %	30,0 %	50,0 %	0,0 %	0,0 %	40,0 %	0,0 %	0,0 %	0,0 %	90,0 %	80,0 %
	STD/ELP	Stem damage, scratches or wear	V	4		1	0	0	1	0	0	1	0	0	0	1	1

#	SAP (ISO Failure Mode)	Failure/Sub-Failure	Part	Severity	Likelihood of Occurrence	Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
	STD/ELP	Bent stem	V	4		1	0	0	1	0	0	2	0	0	0	2	2
	DOP/FTC /FTO	Wrong initial compression	A	3		0	0	0	2	0	0	0	0	0	0	2	2
	DOP/FTC /FTO	Wrong mechanical connection (wrong travel)	A	3		1	1	2	0	0	0	0	0	0	0	2	1
	DOP	Poor calibration	P	3		1	1	1	1	0	0	1	0	0	0	2	2
24	STD, DOP	**Actuator piston misaligned or otherwise damaged inclusive of diaphragm damage if replicable**	A	**2**	**0,5 %**	0,0 %	10,0 %	20,0 %	70,0 %	0,0 %	0,0 %	50,0 %	0,0 %	0,0 %	0,0 %	90,0 %	90,0 %
	STD	Internal corrosion - piston actuator	A	2		0	0	0	1	0	0	1	0	0	0	1	1
	DOP	Internal misalignment, galling	A	2		0	0	0	1	0	0	1	0	0	0	2	2
	DOP	Wrong engineered / designed actuator	A	2		0	0	0	1	0	0	1	0	0	0	2	2
	STD/DOP	Spring damaged or broken	A	2		0	1	1	2	0	0	1	0	0	0	2	2
	DOP	Spring unlinearity / bent spring	A	2		0	0	1	2	0	0	1	0	0	0	2	2
25	INL, LCP, STD, FTC, FTO	**Complete valve seat or seal failure due to compression, wear or looseness**	V	**4**	**0,3 %**	12,5 %	18,8 %	18,8 %	43,8 %	0,0 %	25,0 %	56,3 %	50,0 %	37,5 %	0,0 %	56,3 %	50,0 %
	INL	Internal leakage valve open	V	3		0	0	0	0	0	2	0	2	0	0	0	0
	LCP	Internal leakage valve closed	V	3		0	0	0	0	0	2	0	2	2	0	1	0
	STD	Internal body corrosion/ erosion	V	3		0	0	0	0	0	0	0	0	0	0	0	0
	STD	Internal trim corrosion/erosion	V	4		0	0	0	0	0	0	1	1	1	0	1	1
	STD	Internal trim misalignment, galling	V	4		0	0	0	2	0	0	2	1	1	0	2	2
	STD	Internal trim damage	V	4		0	1	1	1	0	0	2	2	2	0	1	1
	FTC/FTO	High friction, scaling etc.	V	4		0	1	1	2	0	0	2	0	0	0	2	2
	FTC/FTO	Stick-slip effect	V	3		2	1	1	2	0	0	2	0	0	0	2	2

Result		Visual Inspection	Limit Switch	Position Transmitter	Actuator Pressure Sensor	Solenoid Pressure Sensor	Static Cavity Pressure Sensor	Strain Sensor	Dynamic Pressure Sensor	Acoustic Sensor	Process Data	Valve Diagnostic Tool (VDT)	Positioner
Result	**95,2 %**	**40,7 %**	**9,5 %**	**17,1 %**	**49,3 %**	**4,7 %**	**4,0 %**	**43,9 %**	**12,6 %**	**15,5 %**	**1,4 %**	**63,6 %**	**59,1 %**

4.2. FMSA Interpretation

This section gives an interpretation of the sensor data found in the FMSA. Each monitoring method will be discussed separately regarding the failures and sub-failures found in the analysis.

4.2.1. Visual Inspection

The first monitoring column in the FMSA is the activity "Visual Inspection". This is a part of the operations- and maintenance strategy on every staffed oil and gas installation, and involves all visual inspection activities, including visual troubleshooting. The column is intended as a comparison to the different sensors, which includes the possibility for sensors to substitute some of the visual inspection routines. Additionally, visual inspection is not a continuously CM method and requires more human labor than continuous CM with sensors.

As seen in the FMSA, visual inspection is a common method to discover failures like external leakages, external corrosion and other external damages. Additionally, some functional abnormalities can be discovered if they are severe enough. For example, "slip-stick" effect, poor calibration, wrong travel and some abnormal noise. Visual inspection can in other words discover some of the most safety critical failures, if it is conducted regularly or when trouble shooting.

4.2.2. Limit Switch

A limit switch is mounted on all the SCV's, to determine if the valve is in an open or closed position. Additionally, one can determine the travel time from closed to open position and the opposite.

Limit switches are not intended as a CM tool in normal process operation, but rather a position confirmation and feedback to the process operators when the valve is operated. They can indicate a delay of operation, but not the underlying cause. For example, as a result of changed travel time, the limit switches can give an indication of abnormalities related to functional failures. An example of this is high friction and scaling in the valve, which normally will increase the travel time.

4.2.3. Position Transmitter

A position transmitter can determine the position of the valve all the way from closed to open position and opposite. It may therefore give more feedback than limit switches, because it monitors exactly where the valve stops when it is operated. A position transmitter can indicate failures related to the valve and actuator movement, but not the underlying cause. Example of such failures are “slip-stick” effect, poor calibration or indication of internal damages in the valve or actuator (mostly severity 2 and 3). A position transmitter is normally used on control valves and not on/off-valves since they will not regulate the flow, but rather be fully open or fully closed. Equinor has not put position transmitters on the topside SCV’s at Johan Sverdrup.

4.2.4. Pressure Sensor – Actuator

A static pressure sensor on the actuator monitors the pressure inside the actuator. It is therefore a good indication both under normal process conditions (constant actuator pressure) and when operating the valve (varying actuator pressure). In total, an actuator pressure sensor has a coverage indication factor of 49.3% in the FMSA, which in this context is regarded as very useful. Actuator pressure sensors are installed on all topside SCV’s at Johan Sverdrup.

As seen in the FMSA, an actuator pressure sensor can in several cases give precise indications of failures during normal process conditions. As a continuous CM tool, it can discover if the actuator pressure unintendedly decreases, which again can lead to an unintended shutdown (severity 3). There may be several reasons for such an actuator pressure decrease. It could be an external or internal actuator leakage, failing control system components or if the filter regulator has a wrong adjusted set pressure. Several of these sub-failures can be detected early, which in principle means that the error can be categorized as a DD-failure instead of a DU-failure.

When operating the valve, the actuator pressure sensor can discover abnormalities during the valve stroke. If the actuator pressure is very uneven when stroking the valve, it can indicate uneven friction from valve, which again can be caused by scaling, trim damage, internal trim misalignment/galling or a damaged valve stem. An actuator pressure sensor gives a relatively good indication on all of the top five failures in the FMSA, which is counted as the root cause of a failure on automated valve 68% of the time. [28, p. 27]

4.2.5. Pressure Sensor – Solenoid

A solenoid pressure sensor can indicate if the solenoid has a reduced performance. For instance, if it is stuck, has a blocked exhaust or has an insufficient air supply. This can further lead to a disturbance when operating the valve (severity 2) or in worst case an unintended process shutdown (category 3). Nevertheless, a solenoid pressure sensor is in total not that useful as a continuous CM tool and has only a coverage indication of 4.7% in the FMSA.

4.2.6. Pressure Sensor - Valve Cavity

A static cavity pressure sensor is normally mounted through a bleed valve on the valve cavity. It has a coverage factor of only 4.0% in the FMSA and is not intended as a continuous CM tool. However, it is a very useful tool when conducting internal leak testing. The cavity pressure sensor will be discussed further in Chapter 4.3.4, which addresses the utilization of this sensor for leak testing.

4.2.7. Strain Sensor

A strain sensor is intended to monitor mechanical performance both for the actuator and the valve. Like the actuator pressure sensor, a strain sensor gives a relatively good indication on all the top five failure categories in the FMSA. In total, it has a coverage indication factor of 43.9%, which implies that it has a good coverage of most of the 25 failure categories. Failures like binding, galling or other degradation of the valve seats can be caused by scaling, which again causes the seats to get stuck. In this way, the friction between the seats and the ball are changed, which can be monitored as torque changes and therefore strain changes on the pedestal/yoke. The torque is therefore representing the stresses and loads the stem is absorbing. The strain sensor can either partially or completely discover mechanical failures which influence the pedestal/yoke strain. Another example is damaged actuator spring, which will influence the operating torque, and therefore the pedestal/yoke strain. This can affect the status of the functional margin, which is the difference between the torque required to move the valve, and the maximum torque from the actuator. The functional margin is crucial for SCV's to function as intended on demand (severity 4). [7]

4.2.8. Dynamic Pressure Sensor

The FMSA indicates that a dynamic pressure sensor is useful to detect internal leakages, which again can indicate trim, corrosion, erosion, scaling, galling or other trim damages. If such errors are large enough, they are categorized as a severity 4. The dynamic leak sensor has a detection score of 2 for internal leakage of valves in open position. If such failures can be detected earlier by a dynamic leak sensor in the cavity and upstream/downstream, the failure can in principle be categorized as a DD-failure instead of a DU-failure.

Dynamic leak sensors are especially useful when it comes to SCV's with two "active seats" (double piston), because the differential pressure between the valve cavity and the process can be measured. This differential pressure gives an indication of seat integrity when the valve is in open position.

4.2.9. Acoustic Leak Sensor

An acoustic leak sensor can indicate many of the same failures as a dynamic leak sensor. Nevertheless, it has some advantages regarding external leakages, both from the valve and the actuator. An external leakage from an actuator can be discovered at an earlier stage, and potentially an unintended shutdown (severity 3) can be avoided. It can also give an indication of trim damages and internal valve leakages at an early stage, which can re-categorize a DU-failure to a DD-failure.

An acoustic leak sensor is especially useful for CM of SCV's which normally are in a closed position, with a fail open function. An internal leakage can then be discovered at an early stage without the need for a traditional/conventional leakage test.

4.2.10. Process Data

The process data column in the FMSA shows how few sub-failures are detected by process data alone, with a coverage of only 1.4%. It is therefore only meant to compare detection of failures with process data and detection using sensors. Process data may include temperature, flow and pipeline pressure upstream and downstream of the valve. This data is displayed in the control system in CCR and used in the daily operations of the facility.

4.2.11. Valve Diagnostic Tool

The Valve Diagnostic Tool (VDT) is typically used during troubleshooting when a failure/sub-failure has already occurred. It can use and process information from all the sensors, except the dynamic pressure sensor. In order to exploit the potential of the VDT, it is necessary to have several sensors attached to give a good picture of the SCVs condition.

The FMSA shows that a VDT has a total coverage degree of 63.6%. Because a VDT is not a continuous CM tool, it cannot be compared directly with the other sensors, but the FMSA shows the benefits of the tool. An effective troubleshooting tool can potentially decrease the process downtime if an unintended shutdown has occurred due to failure on a SCV.

4.2.12. Positioner

A positioner is a digital valve control unit, which both operates the valve and gives feedback on the behavior. A positioner is not a part of ValveWatch but have some of the same functions. It is included in the FMSA because it can be used as a monitoring tool and not only as a control unit. Approximately all failures regarding operation of the valve can be indicated by a positioner. In total it has a coverage degree of 59.1%, which implies it is very useful in this context. Nevertheless, because a positioner does not measure force or energy in the actuator or stem, but calculates friction based on known parameters like air pressure and drive signal, a positioner will not be suggested or considered at this stage in the project. In addition, it is not part of the already installed ValveWatch system at Johan Sverdrup.

4.3. Matching Sensors and Valves

In appendix A all SCV's are listed with size, actuator type, maintenance activities, function and leak testing, test direction and ValveWatch sensors already installed. This can be used as a tool to determine which sensors a specific valve should have. The sensors recommended is to increase level of surveillance, and in some cases, decrease testing time.

4.3.1. Valve Categories

In the list below, the valves are categorized according to the need for leak testing and if the valve is fail-open or fail-close. ESV's and XSV's are treated the same regarding sensor suggestions, since the difference between them is in the control system and not the mechanical design. The categories are:

- Category 1: Fail open function with required leak testing
- Category 2: Fail close function with required leak testing
- Category 3: Fail open function, no required leak testing
- Category 4: Fail close function, no required leak testing

4.3.2. Sensor Packages

There are different sensors that are useful for the different valve categories. In Table 7 below, the valve categories are assigned relevant sensors to utilize the potential of ValveWatch.

In the FMSA, there is a mixture of sensors and other surveillance methods listed. In Table 7, only the sensors related to ValveWatch is matched with the valve categories. Visual inspection is a useful tool and should be conducted regularly as a part of daily operations to look for external leakages and external corrosion, but it is not a sensor, and is therefore excluded. Process data alone does not properly detect any of the sub-failures. In addition, it is not considered a ValveWatch sensor, and is therefore not included. The positioner is excluded from the table because it is not a ValveWatch sensor and overlap with other sensors which is already installed, such as the actuator pressure sensor. The VDT is a diagnostic tool used during troubleshooting of a valve with clear or suspicious faults. It should therefore be a part of the corrective maintenance strategy, but not as a continuously CM tool at the installation.

Table 7 - Valve categories and sensors

	Actuator Pressure Sensor	Strain Sensor	Acoustic Sensor	Solenoid Pressure Sensor	Dynamic Pressure Sensor	Static Cavity Pressure Sensor
Category 1	YES	YES	YES	NO	NO	YES
Category 2	YES	YES	NO	NO	YES	YES
Category 3	YES	YES	NO	NO	NO	NO
Category 4	YES	YES	NO	NO	NO	NO

4.3.3. Common Features for all Categories

As can be observed in Table 7 above, all valve categories are recommended to have an actuator pressure sensor and a strain sensor. As mentioned earlier, it is already installed an actuator pressure sensor on all the relevant SCV's at Johan Sverdrup, mainly to monitor some of the operational behavior of the SCV's. This decision was made early in the project phase by the maintenance engineering team at Equinor. Thus, this is a further basis for assessment of the relevant sensors in the different categories.

The FMSA shows a clear advantage of a strain sensor in addition to the already installed actuator pressure sensor. The combination of these two sensors, generates an even better overview of the SCV condition. As an example, in Figure 15 below, the actuator pressure (blue) and stem torque (red) are illustrated for a fail-close ESV stroking from closed to open position. As seen in this figure, the pressure increases from 0 seconds (signal initiation) to approximately 10 seconds, when the ball starts moving. Subsequently, a small pressure drop is shown, due to the transition of static to dynamic friction, before an even pressure curve illustrates the movement of the ball. In the end, when the valve is completely open, the pressure increases to the maximum pressure from the filter regulator. It is therefore also indicating if the filter regulator performance is reduced.

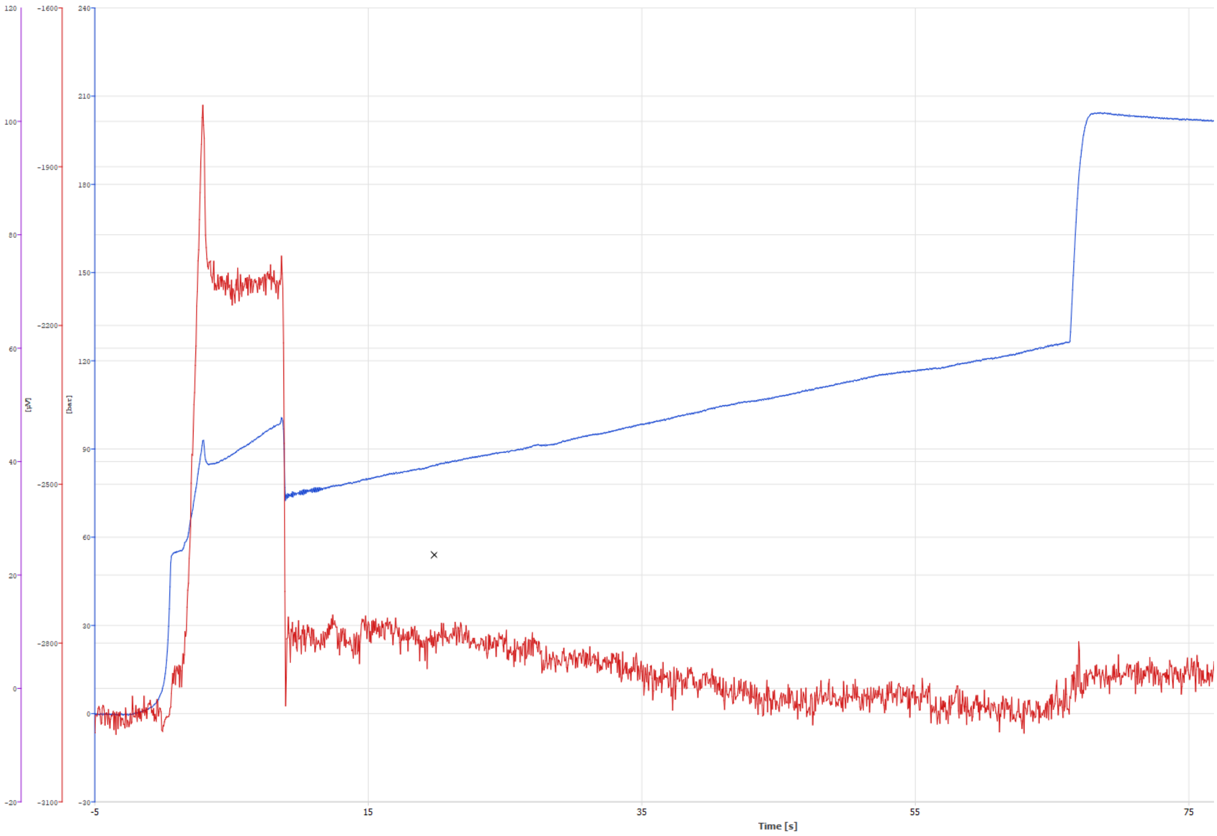

Figure 15 - Actuator pressure (blue graph) and stem torque (red graph) on an ESV traveling from closed to open position [36]

Simultaneously in the start, the stem torque increases until the ball starts moving. During the rest of the stroke, a relatively even torque curve is shown, until a small increase when the valve is completely open. For example, a stick-slip effect during the stroke, would have been visible both due to an uneven pressure and torque curve. In that case, the combination of an actuator pressure sensor and strain sensor could additionally point out if the effect was due to actuator or valve degradation. If the stick-slip effect is caused by an uneven or higher friction from the ball and seats, the valve stem torque will naturally also be more uneven. The reason for this is the reaction forces from the ball and seats, generating a torque through the valve stem, which is monitored as strain by the strain sensor at the pedestal (yoke adapter). On the other hand, if the stick-slip effect is caused by corrosion or galling inside the actuator, the valve stem torque will not vary as much, because the friction does not cause an equally large reaction torque through the valve stem. The stick-slip effect is just one of many different failures and sub-failures in the FMSA, which can be indicated by these sensors. In other words, the combination of these sensors will indicate a failure or sub-failure in the FMSA more precisely, than they do separately. In a CM perspective, earlier and more precise information about the SCV condition is crucial.

In Figure 16 below, another example of a fail-close ESV stroking from open to closed position is shown. It illustrates a typical shutdown, where the valve has a fail-close configuration, due to the decreasing actuator pressure when the valve is closing. The decreasing actuator pressure graph (blue) shows an even pressure when closing. Partial or intermittent sticking of the pneumatic system components would be indicated by that curve, which also is the most likely failure to occur in the FMSA. Degradation of valve seats or trim, which is the second most likely failure to occur in the FMSA, would also be clearly indicated by the two sensors together. This figure also shows a valve travel graph (purple). The graph from the position transmitter can be categorized as redundant, because the actuator pressure sensor also sufficiently indicates the uniformity and positioning of the stroking valve. As mentioned in Chapter 4.2.3 and resulted from the FMSA, the overall evaluation of the position transmitter is relatively low.

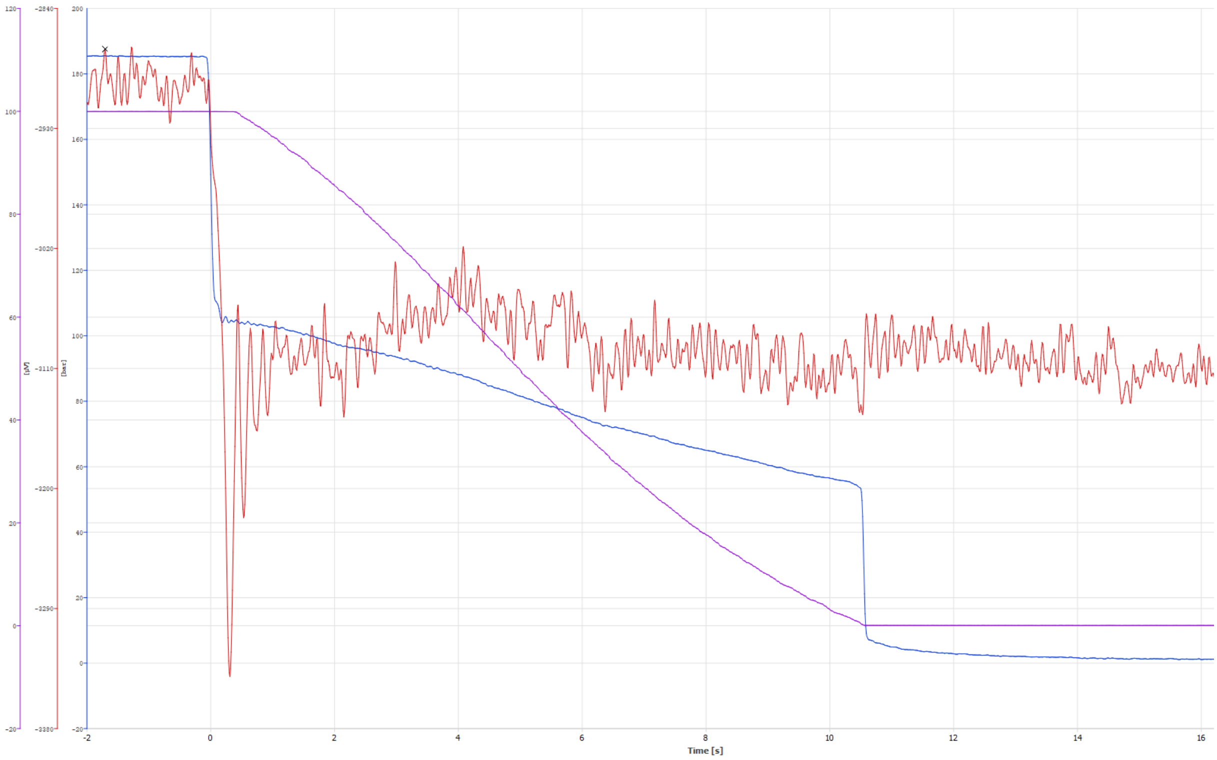

Figure 16 - Actuator pressure (blue graph), stem torque (red graph) and valve travel (purple graph) from open to closed position [36]

Separately, the actuator pressure sensor and strain sensor are the ValveWatch sensors with the highest coverage scores throughout the whole FMSA. Especially for the five most likely failure categories, these sensors are strongly represented. When achieving a better condition overview for the five most likely failures to occur in the FMSA, several of the other failure categories will also be covered. The combination of these sensors can indicate and point out failures and sub-failures more precisely than separately, which can increase safety and prevent unnecessary downtime.

4.3.4. Category 1 - Fail Open Function - Required Leak Testing

Under normal process conditions, SCV’s with a fail open function are in a closed position. This is typically flare or blowdown valves at the installation. In a safety integrity perspective, it is therefore critical to ensure that the SCV will function on demand and that it is not leaking internally. The SCV’s in this category are also required annual leak testing, due to their process and function criticality. It is therefore beneficial to monitor if the valve has an internal leakage during normal process conditions. Such an internal leakage can cause an unplanned shutdown, which again will cause unnecessary production downtime and a non-functioning SIF.

In addition to the common actuator pressure sensor and strain sensor for all valve categories, an acoustic leak sensor is recommended for this valve category. An automatic warning can be activated to highlight if an internal leakage has started at an early stage. It is crucial to discover such a leakage as early as possible, before it is developed to a bigger and more critical leakage. An acoustic sensor is therefore beneficial for a valve which normally is in a closed position. An example of this is shown in Figure 17 below, where an acoustic graph is illustrated. This example is of a pressure safety valve which undergoes an initial pressure surge, maintained leakage and in the end not leaking anymore. The peak of the curve is where the valve is completely open, which is clearly indicated by the acoustic sensor graph. When the valve closes and the leakage decreases, it is uneven (maintained leakage), before closing completely. In other words, an acoustic sensor is ideal to indicate small leakages due to a differential pressure past the valve seats in a closed position. This example illustrates the potential of an acoustic sensor and it can be transferred to an SCV case.

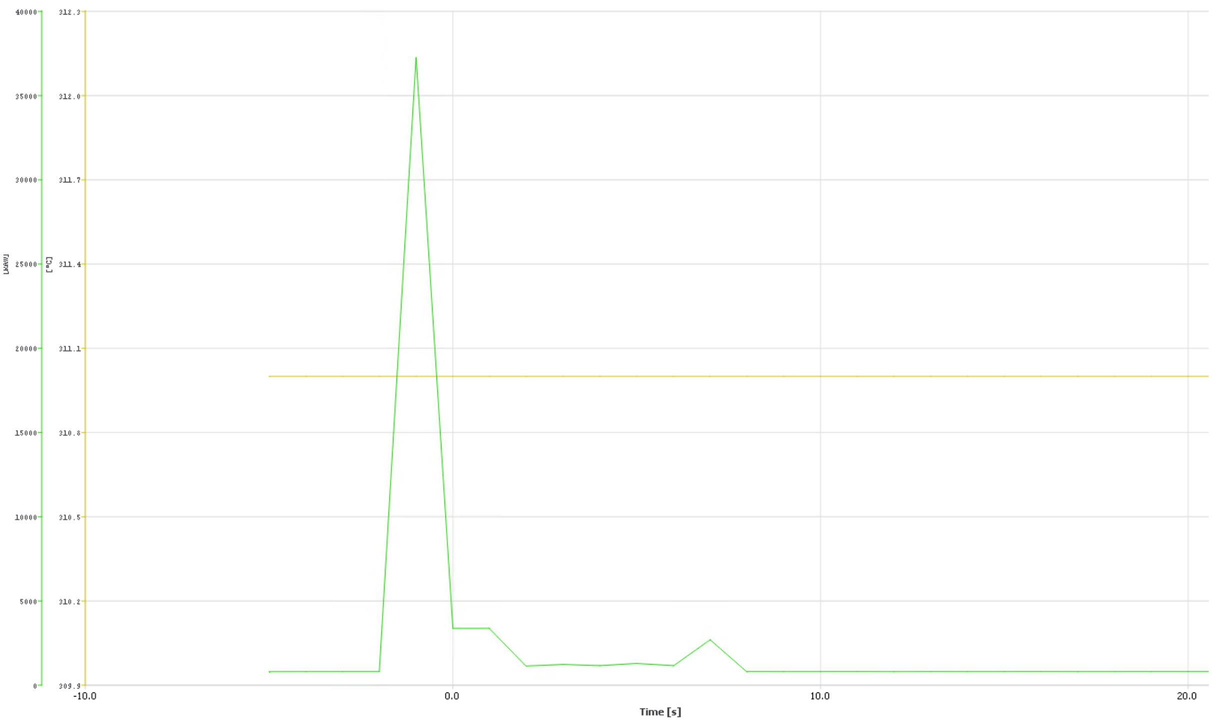

Figure 17 - Acoustic sensor detecting pressure surge and internal leakage in a pressure safety valve [36]

4.3.5. Category 2 - Fail Close Function - Required Leak Testing

This valve category can be compared to category 1, but with fail-close valves. These valves are normally in an open position during production and closes when required for a emergency or process shutdown. Depending on system affiliation and function, a seat leakage can therefore normally not be tested or measured under normal production, without a process shutdown.

Nevertheless, using two dynamic pressure sensors, enables the differential pressure to be measured both in an open and closed position. Measuring the change or disturbance of the cavity pressure compared to the process pressure, can indicate the seat condition. This will again indicate the seat and ball integrity. In other words, the trim sealing condition can be monitored when the valve is in normal production. Even if the exact leakage rate is not measured, it gives a clear indication of seat integrity and condition development over time. When or if the valve closes, a potential valve leakage can also be indicated.

4.3.6. Common Features for Category 1 and 2

An annual leak test is required for valve category 1 and 2. By adding a fixed static pressure sensor to the cavity, instead of a pressure gauge which needs to be attached and continuously monitored by an operator at site, the test can be more streamlined. The potential and suggestion for streamlining will be discussed further in Chapter 5.3.

Related to the technical aspect of adding a static pressure sensor, Figure 18 illustrates a pressurized fail-close ESV stroking from open to closed position. The illustration contains graphs with actuator pressure (blue), valve cavity pressure (purple), downstream pressure (turquoise), upstream pressure (yellow) and stem torque (red). As seen in the figure, the actuator pressure decreases gradually during the stroke, until a small increase right before fully closed position. When fully closed, the actuator pressure is 0 bar, because the actuator spring force is closing the valve. Simultaneously, the stem torque drops when the ball starts to move, then increases in the end of the stroke and peaks when the valve is fully closed. When fully closed, the peak is from the spring force transferring a torque through the valve stem to the ball, which is monitored by the strain sensor at the pedestal/yoke. The actuator pressure and stem torque increase in the end of the stroke, is due to the pressure build-up in the cavity and upstream valve side. This pressure build-up increases the reaction forces generated by the ball and valve seats.

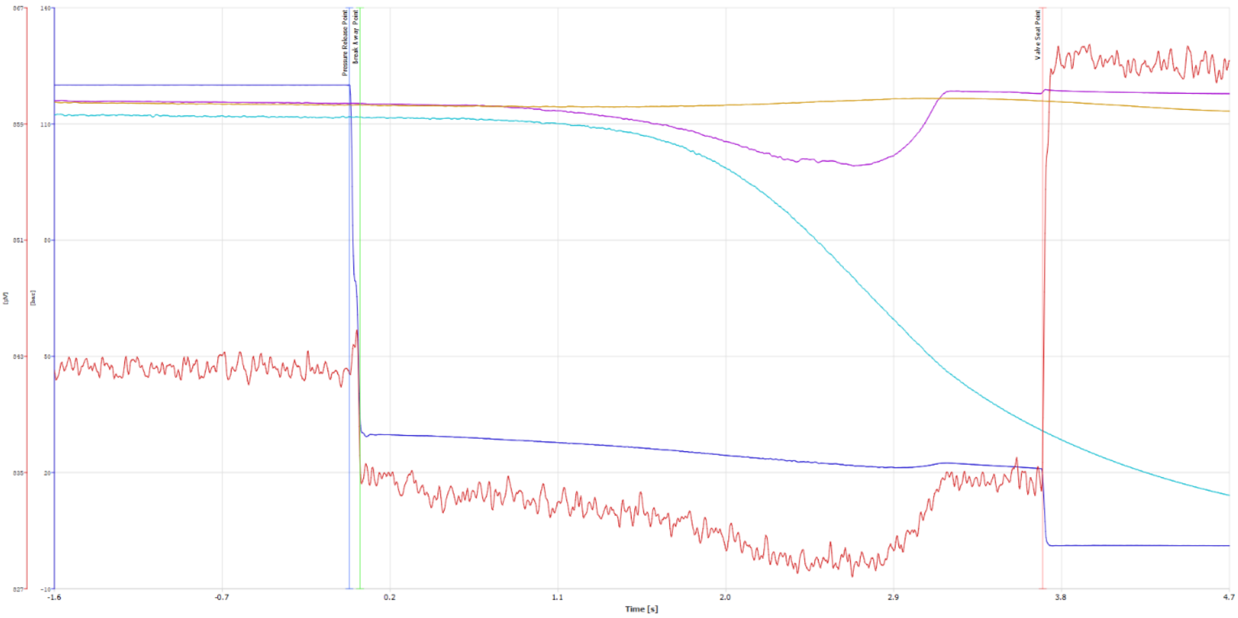

Figure 18 - Actuator pressure (blue graph), stem torque (red graph), cavity pressure (purple graph), upstream pressure (yellow graph) and downstream pressure (turquoise graph). [36]

Particularly interesting for category 1 and 2, is the graphs generated by the static pressure sensors, placed upstream, downstream and in the valve cavity. As seen in the FMSA, the static pressure sensor is beneficial to detect internal leakage when conducting leak testing. Such a leakage is typically generated by failures like internal trim damage, corrosion, misalignment or galling. As seen in Figure 18 above, the downstream pressure decreases because of the closing valve. If the valve had an internal leakage, this pressure would not necessarily decrease, depending on the leakage size. Simultaneously, the cavity pressure decreases during the valve stroke, due to the reduced differential pressure, and increases again when the valve is closed completely. The upstream pressure, on the other hand, only changes slightly because it is the same pressure on the upstream side both before and after the valve stroke. This example contains three static pressure sensors, as a comparison of sensor placement.

Nevertheless, only one static sensor fixed to the valve cavity will be enough to benefit for a leak test. The typical valve seat design at the SCV's at Johan Sverdrup makes it possible to both test the upstream and downstream seat, using a static cavity pressure sensor. One way to do that with a cavity pressure sensor, is by pressurizing the upstream valve side and monitor the unpressurized cavity, to test the upstream seat integrity. For testing the downstream seat integrity, the same can be done, but also pressurizing the valve cavity against the unpressurized downstream side. The cavity pressure is subsequently monitored using ValveWatch, which generates a graph with actuator pressure, stem torque, cavity pressure and time. Potentially, several SCV's can be leak tested at the same time, and the production shutdown can be more streamlined, saving time and costs.

4.3.7. Category 3 & 4 - Fail Open/Close Function - No Required Leak Testing

The two last valve categories are the SCV's with fail- open or -close function, but not required a yearly leak testing. Because these valves are not categorized to be critical enough to conduct the yearly leakage test, they do not need to have internal leakage monitoring. Referring to Table 7, it is therefore only recommended to have an actuator pressure sensor and strain sensor on these valves. The benefits and examples of an actuator pressure sensor combined with a strain sensor, are explained in Chapter 4.3.3. Nevertheless, if evaluated and desired by Equinor, an acoustic sensor or dynamic leak sensor can be implemented on the same basis as category 1 and 2.

4.4. Potential Savings Estimate

The main goal for the Norwegian oil and gas production is to gain the largest possible value from the resources at the NCS. This also includes a highest possible profit for the Norwegian Government and oil and gas companies. With an expansion of the CM program on SCV's, not only will the overall safety of the system be increased, but down-time regarding testing of the SCV's can be decreased.

When producing a maximum of 660,000 barrels per day and an assumed oil price of 70 USD per barrel, one day of downtime will cost:

$$Loss\ of\ revenue = \frac{660000bbl}{day} \cdot \frac{70USD}{bbl} = 46.2\ million\ USD$$

This means that there are major savings involved if downtime is reduced. By reducing the time it takes to perform leak and function tests on SCV's by 1 hour each year for the lifetime of the field (50 years), there is potential for major savings. Assuming a lower production, due to reduced oil production as the amount of oil in the level decrease. An average oil production of 450,000 barrels per day is assumed.

$$Revenue\ per\ hour = \frac{450000\,\frac{bbl}{day}}{24\,\frac{hour}{day}} \cdot \frac{70USD}{bbl} = 1.31\ million\,\frac{USD}{hour}$$

The graph below shows the potential savings as a function of time in hours. From Figure 19 below it becomes apparent that there are major savings to be done by investing in additional sensors to assist in the testing of SCV's.

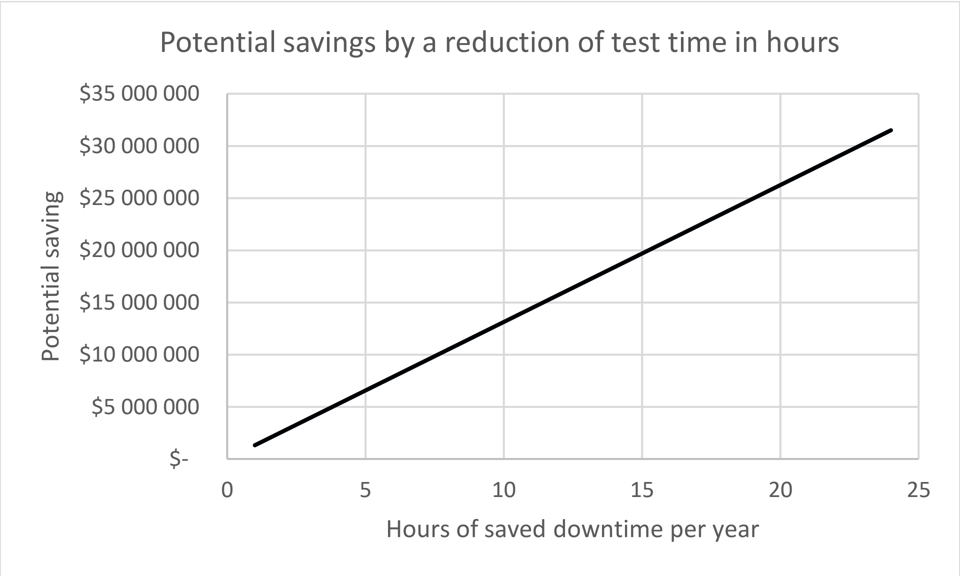

Figure 19 - Potential savings by a reduction of test time in hours

The cost savings by reduced testing time by 1 hour per year for 50 years will be:

$$Cost\ saving, 50\ years = 1.31\ million \frac{USD}{hour} \cdot 1 \frac{hour}{year} \cdot 50 years = 65.6\ million\ USD$$

There are major potentials for savings by expanding the condition monitoring program. Failures will be detected earlier, reduced time for testing and easier troubleshooting will all contribute in reducing costs associated with the testing of SCV’s.

5. Discussion

5.1. Expansion of the CM Program

By matching the failure modes and mechanisms most likely to occur with ValveWatch sensors, it becomes evident which type of sensors is most useful to detect failures. Most of the failures and sub-failures in the FMSA can be detected by one or more sensors. However, it is dependent on the severity of the failure. If the failure is very minor, there is a possibility that no sensors will detect it and the failure must become more severe before it can be detected. Several of the failures in the FMSA are similar, but with different severity. By monitoring and indicating the failures at an earlier stage, they will also be covered at a higher severity stage.

Another aspect to consider is which of the sub-failures occur, where some of the sub-failures is more likely to occur than others. Likelihood of occurrence for each sub-failure is not listed in the FMSA, due to lack of data connected to each sub-failure. The FMSA was created to show which failures and sub-failures the sensors could detect, and then be able to show how several sensors could be used to detect more failures, be able to pinpoint which failure actually happens and to show how the existing modes of surveillance was severely lacking. Additionally, the combination of the sensors can pinpoint failure development at an earlier stage. This leads back to one of the basic principles of CM, which involves detecting error development as early as possible.

With more sensors to monitor the SCV's, a more complete picture of the valve condition is obtained. The different sensors all have their strengths and limitations, and by combining them, the overall coverage of potential failures increases. Additionally, the different SCV's have different needs for surveillance. Leak test required SCV's with a fail-open function will benefit from an acoustic sensor to detect leakage through the valve in closed position. For leak test required SCV's with a fail-close function, a dynamic pressure sensor could be useful to detect internal damage to the valve that can cause loss of function.

In general, there is a lot of interest in this thesis in Equinor, because the thesis connects technical safety, maintenance planning, operations and field instrumentation. When connecting all these areas of expertise, the potential for CM on SCV's becomes apparent. By implementing more sensors on the SCV's can set the precedent for using ValveWatch on other valves, for instance pressure relief valves and check valves. It is therefore suggested to use the results and experience from this thesis and adapt it to other valve types and installations. A potential savings estimate can be increased when including other valves that require testing and monitoring. The economic potential due to increased reliability and equipment condition control, is therefore significant. CM as part of predictive maintenance, is crucial for the development in the oil and gas industry towards unmanned platforms and more subsea installations.

5.2. Increased Barrier Control

According to the FMSA, it becomes apparent that valves with a high level of criticality will benefit from an expansion in the CM program. If the SCV's do not function as intended, the barrier is not maintained. In general, with more sensors on the SCV's and an adapted maintenance strategy, the reliability of the SIF and failure detection is increased. Should a failure occur, it is possible to detect the failure before it becomes a severity 3 or 4 failure. The sensors will also be of assistance during troubleshooting to detect how and why the valve has a reduced performance. This will return the SIF to a safe state in a shorter amount of time.

Without any sensors, the only means of monitoring a SCV is partially by process data and visual inspection. In the FMSA, visual inspection has a coverage degree of 40,7%. However, this is mostly used for troubleshooting and the failures that can be detected is external corrosion, external leakage and stick-slip effect and to some degree calibration issues and stem damage. These sub-failures are recurrent for almost all the failures, meaning that it is not an effective way to monitor a valve. Detection of these sub-failures will not give an accurate image of the condition of the valve.

Another safety aspect to consider when using CM on equipment, is the decreased involvement of personnel. For example, instead of visual monitoring at site when function testing a valve, the test can be monitored remotely through ValveWatch. This means no need for an operator nearby the valve when testing, which again leads to increased safety for personnel due to less time in a potentially hazardous environment. The decrease of involvement from personnel is also an important benefit to consider, when planning towards unmanned monitoring or even unmanned installations.

5.3. Streamlining Testing of SCV

In addition to CM, ValveWatch is intended as a testing and troubleshooting tool for the SCV's at Johan Sverdrup. When a failure is discovered either during continuous CM or testing, the severity is analyzed, automatically or by personnel, and a decision is made for when and how to fix the error. If or when a process shutdown is required, each minute can be precious, due to loss of production at the installation. This also applies for the SCV's which are planned to be function and leak tested annually. Some of these SCV's requires a full production shutdown to be tested, dependent on process function and placement, and it is therefore a high interest in cutting the downtime as much as possible. The production shutdown time per year should be as low as possible and at the same time as high as necessary, to conduct required testing.

5.3.1. Full Stroke Testing

All the SCV's at Johan Sverdrup are planned to have a FST at least once a year. This is due to SIL-requirements and regulations from PSAN, which implies that contributors to risk and HSE are under control and monitored, both overall and individually. By expanding the use of ValveWatch with the recommended sensors in each valve category, more data about the SCV condition can be gained when testing. In other words, each test can give more information about the SCV condition, when conducting function testing with the recommended sensors. A function test without CM sensors, typically consists of travel time measurement and end position confirmation, using limit switch and the installations OPC. In this way, the travel time and full stroke requirements are measured to confirm the SCV integrity. Additionally, one operator should be at site to visually monitor any abnormalities, which can be detected by visual inspection. This method has some limitations, because several of the failures and sub-failures listed in the FMSA, are not completely covered. By adding the recommended sensors in each valve category, more potential degradations will be covered, when conducting function testing.

Another important aspect to consider is the general CM of the SCV's, when or if it is operated in addition to the required function testing. For example, when an emergency shutdown has occurred and it is sufficiently monitored, equal to a function test, it can potentially replace the next functional test. This is dependent on the acceptance criteria, SIL-requirements and related test intervals, but it presents a potential to decrease the production downtime due to an extended function test interval.

5.3.2. Partial Stroke Testing

PST may also have a greater potential if conducted with the suggested sensors and utilization of ValveWatch. Because some SCV's need a production shutdown to be tested, a PST provide preventive maintenance and supplement to a FST. When conducting PST regularly in addition to the annual FST, it can potentially provide earlier detection of failures, associated with SCV function. Earlier detection of degradations will provide a "movement" of DU categorized failures into DD categorized failures. This is essential when conducting preventive maintenance.

Even though PST is not an established practice at Johan Sverdrup yet, the potential may be significant, when performed with CM. In a perspective of three to five years, when sufficient specific equipment experience is obtained, PST may also provide a FST interval extension. This must be analyzed and calculated in regard to relevant requirements, standards and guidelines. However, it has a great potential to increase safety through a better equipment condition control and decrease downtime caused by testing or unplanned shutdowns. This is still a controversial topic, but through further research, equipment experience and CM sensor optimization at Johan Sverdrup, PST may be a key element for the maintenance strategy of the SCV's in the following years. Implementation of the recommended sensors in the valve categories can therefore facilitate this development.

5.3.3. Leak Testing

When installing the sensors in the different valve categories, the function and leak testing can be performed more efficiently and with a more accurate status of the SCV condition. The operations team at the Johan Sverdrup project sees a particularly great potential in streamlining the annual leak testing. As mentioned earlier, the leak testing demands some human labor to mount a pressure gauge and monitor the pressure build-up during a given time for all the SCV's which requires leakage testing. With a fixed mounted static pressure sensor to the valve cavity, the human labor demand is reduced significantly in addition to the greater possibility of testing many more valves at the same time. This can reduce the total production downtime, caused by annual leak testing.

The recommended dynamic pressure sensors and acoustic sensor in two of the valve categories can also improve the CM of the SCV internal sealing condition. When two or three dynamic pressure sensors are installed on a fail-close valve, a leakage past the valve seats and into the valve cavity can be indicated. This applies not only when the valve is in closed position during a process shutdown, but also in open position, under normal production. For an acoustic sensor, which is recommended for fail-open valves, a leakage past the valve seats can also be discovered under normal process conditions.

For both valve categories, the valve seat integrity can therefore be indicated without having to perform a complete internal leak test and interfere with the production. This method will not give an exact value of the internal leakage, but it can indicate a seat integrity change at an early stage. The leakage condition development and what causes this to happen, is the biggest concern in these cases. A decision can be made to handle the leakage if immediate actions are required. Such immediate actions can be to “shock” the valve, i.e. stroke the valve with differential pressure, or/and to inject cleaning agent through the sealant injection fittings to the valve seats. After this, the seat integrity is monitored again, to see the leakage development.

Both dynamic sensors and an acoustic sensor have the potential to streamline the planned leak testing of SCV’s at Johan Sverdrup. This will make the testing more efficient and more cost effective.

6. Conclusion

The current CM strategy does not fulfill the potential CM has on SCV’s. The analysis presented in this thesis shows that it is possible to gain several benefits by investing in more sensors to monitor the SCV’s. By expanding the CM strategy, failures can be detected before they become so severe that they impact the function of the valve, which can lead to a loss of production and safety barrier (severity 4).

The FMSA presented in Ch. 4.1 clearly illuminate the effectiveness of sensors regarding detection of failures. The analysis was developed in collaboration with MRC Global Norway (ValveWatch vendor), experts on CM within Equinor and the authors’ work experience in processing and valve service. Hence, providing the analysis with a solid foundation for evaluating sensor appropriateness and ability to detect failures.

With sensors like actuator pressure sensor and a strain sensor in place, most of the common functional failures will be detected. Should the valve require leak testing, it is also beneficial to include a static pressure sensor in the cavity of the valve. If the valve is fail-open with required leak testing, a dynamic pressure sensor can detect leakage during normal operations. With a fail-close valve with required leak testing, an acoustic sensor is preferred during normal operations. With sensors in place to assist with leak testing, the downtime needed to perform the annual tests can be decreased and the testing procedure will be simplified. Johan Sverdrup already has installed the actuator pressure sensor on the SCV’s, and the valves and control system is designed to easily expand the CM program.

A consequence of decreased downtime means a potentially major capital saving. The potential savings estimate show that there are large savings involved by performing the leak and function testing of SCV’s more efficiently.

By expanding the CM strategy on SCV’s, the company will have better control of the condition of safety barriers, decreasing testing time and making troubleshooting of faulty valves more efficient. This will change the way monitoring and maintenance is done on SCV’s, where Equinor and Johan Sverdrup will shape the future of CM on actuated on/off-valves.

7. Recommendations for Further Work

7.1. SIL Calculations and Changed Test Intervals

After a few years of production on the Johan Sverdrup field, it will be beneficial to perform a study to see if the testing interval on SCV's can be changed. Historical data from the field and data gathered by ValveWatch will give a good foundation to build a case study for a change of the testing interval. The case study should be based on SIL calculations and how PST can detect many of the failures related to automated valves in combination with sensors. Because of increased failure detection, the testing interval of SCV's might be changed.

7.2. Economic Business Case

A proper economic analysis should be performed to establish the costs and savings related to the expansion of the CM strategy on Johan Sverdrup. Investing in the sensors recommended comes with a cost. To calculate the cost the vendor must be contacted to get a price on the sensors and the cost of the work needed to install it. It is also possible to approach other vendors that deliver the same kind of system.

Potential cost savings is related to a decrease in downtime. To gain a correct image of the savings, the actual decrease in downtime related to the testing of the valve must be calculated based on how many valves need leak testing and how much the test time is decreased per valve. Changes in production, oil price and general inflation must also be accounted for.

7.3. Condition Monitoring on Other Valve Types

The results from the analysis and discussion in this thesis can potentially also be used for other valve types than ESV's and XSV's. An analysis should be conducted to look at the effectiveness of implementing similar CM on valves such as check valves and pressure relief valves. This may also have a great potential of decreasing production downtime, due to more efficient testing and control of valve performance.

7.4. Practical Implementation of the Strategy in Equinor

To utilize the suggested sensor implementation in this thesis, the operation and maintenance strategy needs to be modified for Johan Sverdrup. This includes a collaboration between technical integrity, operations, IOC and vendors. A proper analysis should be made to see how data from ValveWatch can be implemented in the existing control system, and how it can be used during normal operations and not only during troubleshooting.

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APPENDIX A

An overview of all SCV's which currently has ValveWatch installed. It also states which valves is in need of leak testing and if it is possible or necessary to use partial stroke test on the valve. Please note that the overview is not complete, due to the Johan Sverdrup project phase, where the maintenance management plan is still in progress.

	General Information			**Function Testing**				**Leak Testing**		**ValveWatch Sensors currently installed**			
TAG	**Valve Size**	**Actuator Type**	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-20ESV0069		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV0092	10	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV0093	2	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV0098	4	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV0122	10	Pneumatic	0,85000	Full	8760	NA	Close	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV0123	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV0139		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV0152		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1242	4	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV1269		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1292	16	Pneumatic	0,85000	Partial	8760	2920	Close	2	A2 - Permanent drain connection.	Yes	No	No	No

TAG	General Information		(Hours) **Maintenance Duration without prep.**	Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**		**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-20ESV1293	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV1294		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1302	16	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV1303	2	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV1321	4	Pneumatic	0,35000	Full	8760	NA	Open (feil i VFST?)	NA	NA	Yes	No	No	No
A-20ESV1381		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1455	2	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV1469		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1490	6	Pneumatic	0,85000	Full	8760	NA	Close	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV1491	20	Pneumatic	0,85000	Partial	8760	?	Close	2	A2 - Permanent drain connection.	Yes	No	No	No
A-20ESV1492	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV1495		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1502	6	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV1521	4	Pneumatic	0,35000	Full	8760	NA	Open (feil i VFST?)	NA	NA	Yes	No	No	No
A-20ESV1633		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1639		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No

TAG	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-20ESV1769		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV1791	16	Pneumatic	0,85000	Partial	8760	2920	Close	2	A2 - Permanent drain connection.	Yes	No	No	No
A-20ESV2242	4	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV2269		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2292	16	Pneumatic	0,85000	Partial	8760	4380	Close	2	A2 - Permanent drain connection.	Yes	No	No	No
A-20ESV2293	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV2294		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2302	16	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV2303	2	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV2321	4	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV2381		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2455	2	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV2469		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2490	6	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV2491	20	Pneumatic	0,85000	Partial	8760	?	Close	2	A2 - Permanent drain connection.	Yes	No	No	No

TAG	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-20ESV2492	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20ESV2495		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2502	6	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20ESV2521	4	Pneumatic	0,35000	Full	8760	NA	Open (feil i VFST?)	NA	NA	Yes	No	No	No
A-20ESV2633		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2639		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2769		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20ESV2791	16	Pneumatic	0,85000	Partial	8760	2920	Close	2	A2 - Permanent drain connection.	Yes	No	No	No
A-20ESV4051	4	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV4101	4	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV4131	4	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV4201	4	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20ESV4231	4	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-21ESV0087		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-21ESV0126	14	Pneumatic	0,85000	Partial	8760	?	Close	1	A2 - Permanent drain connection.	Yes	Yes	Yes	Yes
A-21ESV1078		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-21ESV1792		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-21ESV2078		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No

	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
TAG	**Valve Size**	**Actuator Type**	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-21ESV2792		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV0024		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV0052		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV0152		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV0254		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV0282		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV0352		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV1511		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV1557		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV1758		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV1777		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV1781	6	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-23ESV1782	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-23ESV1785		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV1790	10	Pneumatic	0,85000	Partial	8760	?	Close	1	A2 - Permanent drain connection.	Yes	Yes	Yes	Yes
A-23ESV1791	4	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-23ESV2557		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-23ESV2758		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No

TAG	General Information		(Hours) **Maintenance Duration without prep.**	Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**		**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-24ESV0055		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-24ESV0138		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-24ESV0252		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-43ESV0039	2	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-43ESV0043	10	Pneumatic	0,35000	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-43ESV0046	28	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-43ESV0096	4	Pneumatic	0,35000	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-43ESV0139	4	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44ESV0213		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-44ESV0540		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-44ESV0571		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-45ESV0025		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-45ESV0205	2	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45ESV0215	2	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45ESV0225	2	Pneumatic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-13ESV0854	14	Hydraulic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-13ESV0857	14	Hydraulic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-13ESV0874	14	Hydraulic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-13ESV0877	14	Hydraulic	0,35000	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-21ESV0130		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-21ESV0132	20	Pneumatic	0,85000	Partial	8760	4380	Close	1	A2 - Permanent drain connection.	Yes	Yes	Yes	Yes
R-21ESV0813		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No

TAG	General Information		(Hours) **Maintenance Duration without prep.**	Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**		**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
R-21ESV0816	20	Pneumatic	0,85000	Partial	8760	4380	Close	1	A2 - Permanent drain connection.	Yes	Yes	Yes	Yes
R-21ESV0817	38	Pneumatic	0,35000	Partial	8760	?	Close	NA	NA	Yes	No	No	No
R-21ESV0823		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-23ESV0001		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0002	8	Pneumatic	0,85000	Full	5840	NA	Close	4	A2 - Temporary drain connection.	Yes	No	No	No
R-27ESV0003		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0005		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0009	2	Pneumatic	0,85000	Full	5840	NA	Close	4	A2 - Temporary drain connection.	Yes	No	No	No
R-27ESV0172		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0181	20	Pneumatic	0,85000	Full	8760		Close	4	A2 - Temporary drain connection.	Yes	No	No	No
R-27ESV0183		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0187		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0407		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
R-27ESV0409	6	Pneumatic	0,85000	Full	5840	NA	Close	5	A2 - Temporary drain connection.	Yes	No	No	No
R-43ESV0079	4	Pneumatic	0,35000	Full	5840	NA	Close	NA	NA	Yes	No	No	No
R-43ESV0139	4	Pneumatic	0,35000	Full	5840	NA	Close	NA	NA	Yes	No	No	No
R-46ESV0034	2	Pneumatic	0,35000	Full	5840	NA	Close	NA	NA	Yes	No	No	No

TAG	General Information		(Hours) **Maintenance Duration without prep.**	Function Testing				Leak Testing		ValveWatch Sensors currently installed			
TAG	**Valve Size**	**Actuator Type**		**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
R-46ESV0044	2	Pneumatic	0,35000	Full	5840	NA	Close	NA	NA	Yes	No	No	No
R-57ESV0073		Pneumatic	0,35000		8760			NA	NA	Yes	No	No	No
A-20XSV0081	12	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20XSV0082	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20XSV0085	10	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20XSV0115	4	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20XSV0138	3	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20XSV0141	8	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20XSV0145	8	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-20XSV0150	4	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-20XSV0151	6	Pneumatic	0,18522	Full	8760	NA	Close	1	A2	Yes	No	No	No
A-20XSV1281	20	Pneumatic	0,85000	Partial	8760	?	Close	2	A2 - Temporary drain connection.	Yes	No	No	No
A-20XSV1282	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20XSV1452	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2 - Temporary drain connection.	Yes	No	No	No
A-20XSV1481	10	Pneumatic	0,85000	Partial	8760	?	Close	2	A2	Yes	No	No	No
A-20XSV1482	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-20XSV1631	20	Pneumatic	0,85000	Partial	8760	2920	Close	2	A2 - Temporary drain connection.	Yes	No	No	No
A-20XSV1781	16	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No

TAG	General Information		(Hours) **Maintenance Duration without prep.**	Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**		**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-20XSV2281	20	Pneumatic	0,85000	Partial	8760	?	Close	2	A2 - Temporary drain connection.	Yes	No	No	No
A-20XSV2282	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-20XSV2452	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-20XSV2481	10	Pneumatic	0,85000	Partial	8760	?	Close	2	A2	Yes	No	No	No
A-20XSV2482	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-20XSV2631	20	Pneumatic	0,85000	Partial	8760	2920	Close	2	A2	Yes	No	No	No
A-20XSV2781	16	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-21XSV1075	8	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-21XSV2075	8	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV0055	14	Pneumatic	0,85000	Partial	8760	?	Close	3	A2	Yes	No	No	No
A-23XSV0155	14	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-23XSV0156	10	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV0157	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV0158	10	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV0159	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV0285	12	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV0355	12	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV1256	6	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV1502	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV1507	3	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV1514	18	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV1515	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No

	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
TAG	Valve Size	Actuator Type	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-23XSV1535	4	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV1536	4	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV1561	10	Pneumatic	0,85000	Partial	8760	?	Close	2	A2	Yes	No	No	No
A-23XSV1562	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-23XSV1675	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV1676	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV1765	8	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV1766	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV1788	4	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV1798	6	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV2256	6	Pneumatic	0,18522	Full	8761	NA	Open	NA	NA	Yes	No	No	No
A-23XSV2502	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV2507	3	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV2514	18	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV2515	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-23XSV2535	4	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV2536	4	Pneumatic	0,18522	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-23XSV2561	10	Pneumatic	0,85000	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV2562	2	Pneumatic	0,85000	Full	8760	NA	Open	3	A2	Yes	No	No	No
A-23XSV2675	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV2676	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-23XSV2765	8	Pneumatic	0,18522	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-23XSV2766	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-24XSV0201	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No

TAG	General Information		(Hours) **Maintenance Duration without prep.**	Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	**Actuator Type**		**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-24XSV0211	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-24XSV0231	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-24XSV0254	4	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-24XSV0301	4	Pneumatic	0,18522	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-24XSV1041	6	Pneumatic	0,18522	Full	8762	NA	Close	NA	NA	Yes	No	No	No
A-24XSV1043	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-24XSV2041	6	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-24XSV2043	2	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-40XSV0013	1	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-40XSV1231	8	Pneumatic	0,18522	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-40XSV2231	8	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-41XSV0011	1	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-41XSV0525	3	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-41XSV1505	6	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-41XSV2505	6	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0598	0,75	Pneumatic	0,18522	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-42XSV0623	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0673	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0723	2	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0805	0,75	Pneumatic	0,18522	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0827	0,75	Pneumatic	0,18522	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0836	0,75	Pneumatic	0,18522	Full	8762	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0838	0,75	Pneumatic	0,18522	Full	8763	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0839	0,75	Pneumatic	0,18522	Full	8764	NA	Close	NA	NA	Yes	No	No	No

TAG	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	Actuator Type	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-42XSV0841	0,75	Pneumatic	0,18522	Full	8765	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0842	0,75	Pneumatic	0,18522	Full	8766	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0857	0,75	Pneumatic	0,185223	Full	8767	NA	Close	NA	NA	Yes	No	No	No
A-42XSV0920	0,75	Pneumatic	0,185223	Full	8768	NA	Close	NA	NA	Yes	No	No	No
A-43XSV0092	2	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-43XSV0094	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0157	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0191	3	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0193	10	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0194	24	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0195	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0216	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0217	24	Pneumatic	0,185223	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-44XSV0218	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0328	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0522	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0543	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0544	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0546	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0547	8	Pneumatic	0,185223	Partial	8760	?	Close	NA	NA	Yes	No	No	No
A-44XSV0573	3	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0575	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0576	4	Pneumatic	0,185223	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0577	4	Pneumatic	0,185223	Full	8762	NA	Close	NA	NA	Yes	No	No	No

TAG	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	Actuator Type	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-44XSV0642	6	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-44XSV0643	6	Pneumatic	0,185223	Full	8761	NA	Open	NA	NA	Yes	No	No	No
A-44XSV0644	6	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-44XSV0647	2	Pneumatic	0,185223	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-44XSV4051	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0018	2	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-45XSV0019	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0110	3	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0119	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0120	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0121	2	Pneumatic	0,185223	Full	8761	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0163	2	Pneumatic	0,185223	Full	8762	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0164	2	Pneumatic	0,185223	Full	8763	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0166	2	Pneumatic	0,185223	Full	8764	NA	Close	NA	NA	Yes	No	No	No
A-45XSV0167	2	Pneumatic	0,185223	Full	8765	NA	Close	NA	NA	Yes	No	No	No
A-46XSV0198	0,75	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-46XSV0199	0,75	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-46XSV0200	0,75	Pneumatic	0,185223	Full	8761	NA	Open	NA	NA	Yes	No	No	No
A-50XSV0330	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-56XSV0306	2	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-57XSV0015	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-57XSV0075	3	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-57XSV0076	3	Pneumatic	0,185223	Full	8760	NA	Open	NA	NA	Yes	No	No	No
A-57XSV0080	3	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No

TAG	General Information			Function Testing				Leak Testing		ValveWatch Sensors currently installed			
	Valve Size	Actuator Type	(Hours) **Maintenance Duration without prep.**	**Stroke Test Type**	(Hours) **Test Interval Func.**	(Hours) **Test Interval PST**	**Test Direction**	(1-100%, 2-50%, 3,4,5-0%) **Shutdown Group**	A1-Cl.Va.Diff.Press, A2-Cl.Va.Cav.Press **Leak Test**	**Actuator Pressure**	**Dynamic Pipeline Leak**	**Dynamic Cavity Leak**	**Strain Gage**
A-64XSV0324	1,5	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-27XSV0174	6	Pneumatic	0,85000	Full	8760	NA	Close	5	A1	Yes	No	No	No
R-27XSV0179	20	Pneumatic	0,85000	Full	8760	NA	Close	4	A2	Yes	No	No	No
R-27XSV0180	2	Pneumatic	0,85000	Full	8760	NA	Close	4	A2	Yes	No	No	No
R-29XSV0207	14	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-29XSV0407	14	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-29XSV0607	14	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-29XSV0807	14	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-42XSV0006	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-42XSV0008	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-50XSV0245	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-56XSV0080	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-56XSV0120	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-57XSV0072	4	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-62XSV0401	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-62XSV0421	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-62XSV0431	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-62XSV0432	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
R-83XSV0003	2	Pneumatic	0,185223	Full	8760	NA	Close	NA	NA	Yes	No	No	No
A-24XSV0151	2	Pneumatic	0,85000	Full	8760	NA	Close	1	A2	Yes	Yes	Yes	Yes