QC-FIT EVALUATION OF WING VALVE FAILURES

Office of Offshore Regulatory Programs

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Bureau of Safety and Environmental Enforcement

EXECUTIVE SUMMARY

On January 20, 2010, a 10 ksi-rated flanged bonnet designed wing valve failed at an Original Equipment Manufacturer's (OEM) test facility. The wing valve was designed for a 3,000-psi hydraulic operating pressure with a qualification test rating of 4,700 psi. During qualification pressure testing, the wing valve's eight fasteners [1] were subjected to excessive pressures, resulting in the disengagement of the fasteners (stripped threads) from the retainer ring which holds the hydraulic operating piston in the actuator. This testing failure also posed a risk of serious injury to manufacturing personnel during qualification testing at the OEM facility.

In response, BSEE assembled a Quality Control Failure Incident Team (QC-FIT) to conduct a technical evaluation of the equipment involved in this incident to determine if there were global quality assurance/quality control (QA/QC), safety, and or environmental concerns that needed to be addressed by the BSEE related to the design and use of wing valves. Specifically, BSEE questioned whether the fasteners' thread engagement into the retainer ring was appropriate and if the wing valve material property values (hardness, yield strength, and ultimate tensile strength) were fit for the intended service. BSEE's technical evaluation included a review of the wing valve design and applicable industry standards, including API 6A *"Specification for Wellhead and Christmas Tree Equipment"* Nineteenth and Twentieth Editions[2], and API 17D *"Design and Operation of Subsea Production Systems - Subsea Wellhead and Tree Equipment"* First and Second editions[3]. The technical evaluation also included the review of the following: data submitted by a third-party; the OEM's failure investigation report, data, and analysis; and the material and design specifications to determine if there were other issues which needed additional action by the industry or BSEE.

The QC-FIT technical evaluation raised the following key concerns:

- Whether there existed design deficiencies that could result in failure during qualification testing, or at other times, which could be a safety risk to personnel;
- Whether the wing valve's design and material mechanical properties (hardness, yield strength, and ultimate tensile strength) were adequate to meet the anticipated operating conditions; and
- Whether the fasteners used to secure the wing valve were appropriate, as per API 6A "Specification for Wellhead and Christmas Tree Equipment" Nineteenth Edition and API 17D "Design and Operation of Subsea Production Systems - Subsea Wellhead and Tree Equipment" Second Edition; and
- Whether changes to industry standard requirements of the minimum thread engagement requirement of one times the outer diameter of the fastener were needed.

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[1] "Studs" are referred to as "fasteners" throughout this report.
[2] API 6A Nineteenth Edition is currently incorporated into BSEE regulations.
[3] API 17D Second Edition is currently incorporated into BSEE regulations.

Key findings include the following:

1. The original OEM specifications designed the wing valve for a hydraulic operating pressure of 3,000 psi and required a qualification test rating of at least 4,500 psi, which is 1.5 times the rated working pressure. The planned qualification test pressures and temperatures were in accordance with API 17D Second Editions, and API 6A Nineteenth Edition. The wing valve was exposed to pressure loading tests at three different sites during manufacture and qualification testing. The OEM's failure investigation indicated that an overpressure occurred during testing at one of the facilities which led to the failure of the wing valve.

2. The OEM's failure analyses showed that a hydraulic operating pressure above the specified qualification test rating of 4,500 psi would be required to produce the type of fastener and housing failure encountered during this test. The overpressure event was attributed to the lack of test fixture over-pressure protection and the lack of automated pressure control.

3. Additional information obtained by BSEE indicated that there was also the possibility of design deficiencies in the wing valve, including lower yield strength (YS) and ultimate tensile strength (UTS) retainer ring material properties [4] and insufficient thread engagement for its intended purpose. BSEE found that a low YS (35 ksi) retainer ring material in combination with a high YS fastener material (105 ksi) along with thread engagement below API Specification 6A and 17D levels, resulted in the stripping of the threads from the retainer ring when pressures above the qualification test rating of 4,500 psi were applied. If the material properties of the retainer ring were a closer match to the fasteners' material, it is unlikely the threads would have stripped out of retainer ring.

4. The fasteners on the failed wing valve had thread engagements ranging from 0.560 – 0.793 inches into the retainer ring. This did not meet the minimum thread engagement requirement of 0.875 inches, one times the outer diameter of the fastener per API 6A (Nineteenth or Twentieth editions) and API 17D (First or Second edition) standards.[5] Insufficient thread engagement can place excess stress on the threads, ultimately causing them to strip. If complete failure does not occur immediately, failure may take place at a later time as cyclic loads add to the stress on the threads.

As a result of the failure, the OEM made design changes to the retainer ring material to reduce the risk of additional failures. However, the OEM may need to consider additional evaluation of

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[4] The OEM noted that the retainer ring material was manufactured to the design specifications and the material properties were within the specified limits. The OEM believes their design was sufficient since they were not designing to the overpressure condition that this failure occurred under.

[5] The OEM disagreed with this statement and believes there was full thread engagement. Due to the fact that the stripped threads measurements did not show the required 0.875 inches engagement into the retainer ring, BSEE believes that the thread engagement did not meet the requirements of API 6A (Nineteenths and Twentieth editions) or 17D (First and Second editions).

the wing valve design to ensure adequate thread engagement into the retainer ring and further reduce the risk of potential future failures.

However, in response to these findings, BSEE has the following recommendations/observations:

Recommendations specific to the horizontal subsea wing valve include:

1. The OEM should consider increasing the required amount of thread engagement into the retainer ring as specified in API 6A, Nineteenth Edition, and required per BSEE regulations in §250.806, to ensure proper closure bolting.

Recommendations applicable to wing valves, in general, include:

1. Industry should consider funding a joint-industry project to evaluate wing valve design, manufacturing processes, and material property requirements. This joint-industry project should include an analysis of optimal thread engagement, optimal material properties, and load designs for wing valves.

2. Industry should evaluate wing valve designs to ensure the material properties (e.g. yield strength) closely match and acceptable stress levels are achieved. Retainer ring material properties should be compared to fastener material properties to ensure consistent load paths, adequate closure bolting, and verify that the valve is fit for service.

3. Industry should evaluate wing valve fastener thread engagement and interface tolerances to ensure proper closure bolting. Wing valve designs should provide adequate allowance for thread engagement and manufacturing procedures should be evaluated to verify proper thread engagement prior to qualification testing.

4. BSEE should require operators to provide supporting documentation detailing why a wing valve is not required to meet API 6A Nineteenth Edition or 17D Second edition for thread engagement as part of a production plan or Deep Water Operations Plan (DWOP).

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BACKGROUND

A wing valve is a piece of flow-control equipment used in oil and gas operations. It is part of a Christmas tree and used to shut in flow from a producing well. A Christmas tree is typically fitted with two wing valves, one on each side. Hydraulic tree wing valves are designed to be failsafe valves and require the application of hydraulic pressure to remain open. If minimum operating pressure is not maintained, the valve automatically closes, preventing a release of hydrocarbons to the environment.

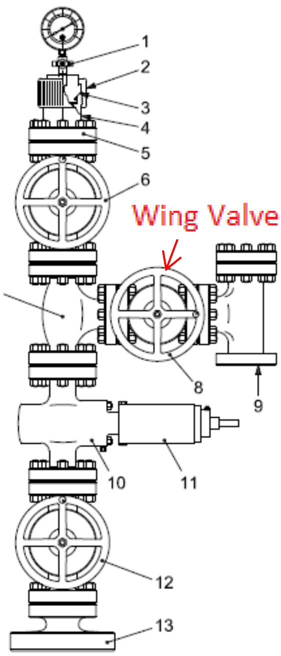


Figure 1: API Spec. 6A, Typical Christmas Tree

Subsea and surface trees have a large variety of valve configurations, including combinations of manual and actuated (hydraulic or pneumatic) valves. Examples of subsea and surface trees are identified in API Specification 6A, Twentieth Edition, *"Specification for Wellhead and Christmas Tree Equipment"* published in 2011 and API Specification 17D, Second Edition *"Design and Operation of Subsea Production Systems-Subsea Wellhead and Tree Equipment"* published in 2011. A basic surface tree, which can be seen in Figure 1, consists of two or three manual valves. A sophisticated surface tree will have at least four or five valves, normally arranged in a cross-type pattern. These trees consist of upper and lower master valves, actuated wing valves, and swab valves.

The subsea wellhead system provides a means to hang off and seal off casing during the drilling of a well. The wellhead system also provides a profile for latching the subsea blowout preventer stack and drilling riser, providing a flow conduit to the floating drilling rig. During the production phase of the well, the subsea wellhead system provides secure access to the wellbore in a pressure-controlled environment. Subsea tree configurations vary depending on wellhead type, service conditions, well shut-in pressure, water depth, reservoir parameters, environmental factors, and operational requirements. They contain more valves and accessories compared to surface trees and are available in either vertical or horizontal configurations. Typically, subsea trees are comprised of chokes, valves, a flowline connection interface, subsea control interfaces, and sensors for data collection.

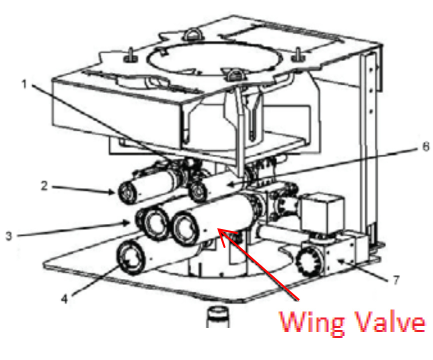


Figure 2: API Spec 17D, Vertical Tree

Vertical subsea trees (Figure 2) are installed either on the wellhead or on a tubing head after the subsea tubing hanger has been installed. The production flow path during workover operations runs through the valves mounted in the vertical bore of the subsea tree. The production flow path during production (injection) runs through the production outlet that branches off the vertical bore. The subsea tree may have a concentric bore or multiple bores. Annular access may be through one of the tree bores or through a side outlet in the tubing head below the tubing hanger. The production outlet may be located at 90 degrees to the production bore or may be angled to best suit flow requirements.

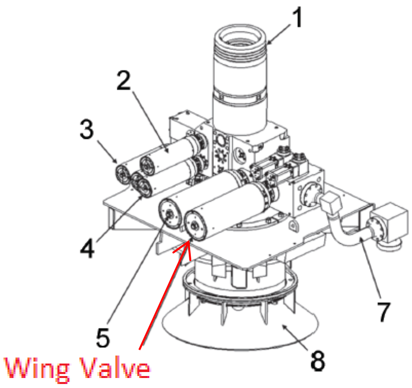


Figure 3: API SPEC 17D, Horizontal Tree

Horizontal subsea trees (Figure 3) use many of the same components as vertical trees; however, some of the equipment differs significantly from that used in vertical trees. Horizontal tree arrangements offer different benefits in regards to installation, retrieval, and maintenance. Horizontal trees may also be used with mudline suspension equipment and drill-through mudline suspension equipment and may be configured for artificial lift completions such as electric or hydraulic submersible pumps. The wing valve evaluated in this report is a failsafe valve used on a horizontal subsea tree. Figure 4 shows a schematic of the wing valve with the location of the failed fasteners.

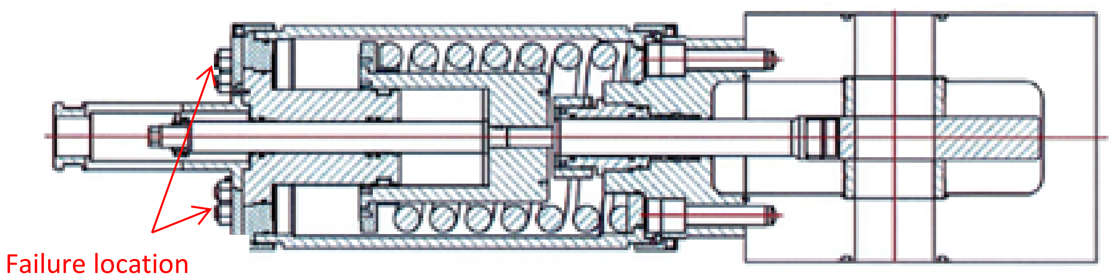


Figure 4: Failed wing valve

ASSESSMENT

As a result of a failure that endangered manufacturing personnel during qualification testing of a wing valve, a third party informed BSEE about QA/QC and safety concerns with the wing valve's materials and the OEM's test procedures. The third party raised specific concerns about the wing valve's material property values and whether the design and testing procedures were in compliance with industry standards (API 17D First Edition, October 1992). In response, the BSEE convened a QC-FIT within the Office of Offshore Regulatory Programs to evaluate any QA/QC and safety concerns associated with the use of wing valves on the Outer Continental Shelf (OCS) and to determine if there were global industry-wide issues involving wing valve equipment or manufacturing processes that needed further action by BSEE or the industry.

As part of the evaluation, the QC-FIT was tasked to do the following:

1) Verify the accuracy of the OEM's wing valve design and qualification testing procedures;
2) Determine the applicability of data provided by the third party to BSEE's mission; and
3) Determine the potential impact an incident involving this equipment may have on the OCS.

BSEE worked with the OEM throughout this evaluation to assure that any potential offshore safety issues were identified and addressed. The QC-FIT reviewed the wing valve's design based on data provided by both the OEM and the third party to determine if there were outstanding issues regarding the design and its fitness for service. A general schematic of the failed wing valve can be seen below in figure 5.

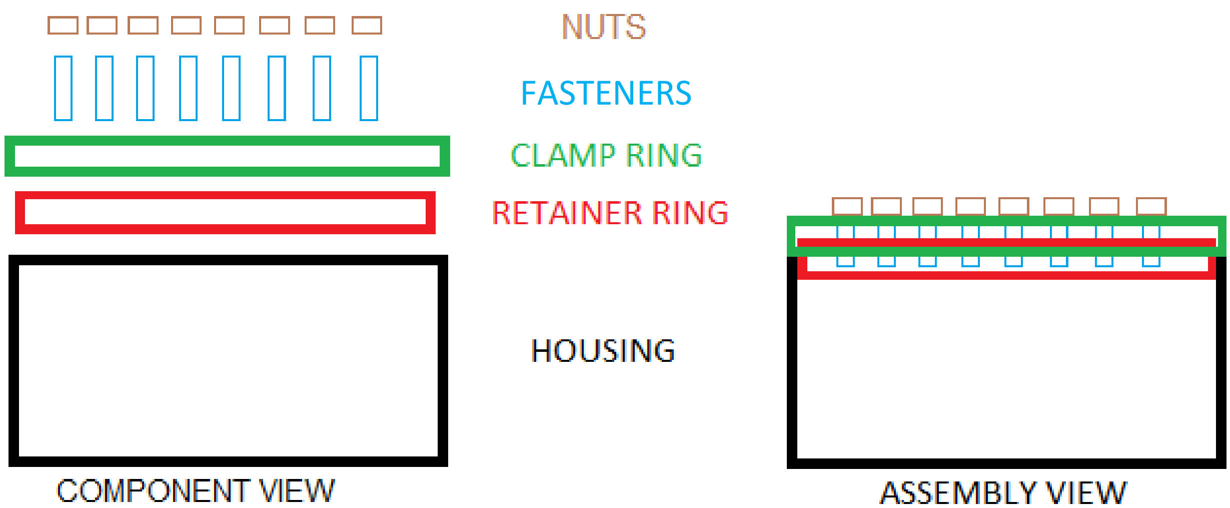


Figure 5: Wing Valve and Terminology
Additional detail and terminology for the wing valve can be seen in the appendix

The QC-FIT evaluated available data from documents provided by the third party, from the OEM and additional information provided in response to BSEE's questions. BSEE contracted Argonne National Laboratory (ANL), to perform an analysis of the data and serve as an independent evaluator of this incident. ANL's findings matched the QC-FIT findings for this evaluation.

Although the failure described did not occur on the OCS, wing valves are used on the OCS and globally. The OEM noted there was at least one Christmas tree currently installed on the OCS containing two of the affected wing valves, and similar valves were shipped globally. Therefore, the appropriate design and fitness for service of the wing valve was important and could potentially impact operation, safety and the environment on a global scale.

ORIGINAL EQUIPMENT MANUFACTURER (OEM) ROOT CAUSE ANALYSIS (RCA)

In response to the wing valve failure, the OEM performed an internal root-cause analysis (RCA). The OEM determined that the root cause of the incident was the accidental over-pressurization of the wing valve during manufacturing qualification testing. According to the OEM, over-pressurization of the equipment during qualification testing occurred previously on three separate occasions; however, the OEM did not take actions robust enough to prevent reoccurrences. No additional information was provided to BSEE about the prior incidents. Based on the RCA findings, the OEM made the following changes:

1) Increased material strength for the retainer rings;
2) Revised interface tolerances on the housing and clamp ring to provide more consistency in the load path; and

3) Provided additional personnel training on test procedures.

The wing valve was designed to function normally with a 3,000-psi operating pressure. The test pressure required by the OEM during manufacturing qualification testing was at least 1.5 times the rated working pressure, in accordance with API 17D First Edition. This equated to a minimum test pressure rating of 4,500 psi (the OEM used 4,700 psi). The OEM calculated their test rating using a worst-case scenario in which all eight fasteners had a thread engagement of 0.5 inches and determined that a pressure greater than the qualification test rating of 4,700 psi was required to strip the threads, as seen in figure 6. The OEM was unable to determine the range of over-pressure required to fail the wing valve.

Figure 6: Stripped threads in the retainer ring and depth of thread engagement

THIRD–PARTY

A third party provided additional data to BSEE indicating that lower safety factors were used during the qualification testing than those calculated by the OEM. A safety factor is a ratio between the maximum applied stress that a piece of equipment can sustain without damage, and the anticipated stress the equipment will experience while in service. The units for a safety factor are dimensionless. For the worst-case scenario of a minimum thread engagement (0.5 inches) for all eight fasteners, the OEM presented a safety factor value of 1.2. However, the third party provided calculations with multiple safety factors values of less than 1.0 for a worst-case scenario (values as low as 0.498 safety factor). A safety factor of less than 1.0 indicates that the wing valve could plastically yield or potentially fail under the anticipated operating conditions for which it was rated (rendering it not fit for service).

Figure 7: Failed Fasteners and stripped threads

In this case, the safety factors were calculated with the material yield shear strength rather than with the material ultimate shear strength. If safety factors with respect to yield shear strength were less than 1.0, then the threads would yield but not necessarily fail. Conversely, if the safety factors with respect to ultimate shear strength were less than 1.0, the threads would fail. The failed fasteners can be seen in Figure 7. In both cases, the safety factors should be greater than 1.0, as an appropriate engineering measure of safety, to ensure that the equipment can withstand the required pressures.

FINDINGS

Based on analyses conducted by the OEM and the third party, the BSEE QC-FIT team identified two issues with the wing valve design.

1) There was a large difference in the material property values between the fasteners and the retainer ring (Figure 5). The fasteners had a material yield strength value of 105 ksi, while the retainer ring's material yield strength value was 35 ksi (a difference of 70 ksi). As a result, in an over-pressurization situation, the contact area between the fasteners and retainer ring (i.e., the thread engagement of the fasteners into the retainer ring) could cause the retainer ring material to fail first. This failure would result in the retainer ring threads becoming stripped while the fasteners' threads remained intact (Figures 6 & 7). The OEM confirmed the large difference in yield strength values between the fasteners and the retainer ring. The OEM also noted that the difference in material yield strength values did not play a role in the failure because the material properties were sufficient for the anticipated load rating of the wing valve. Since the time the third party reported the incident, the OEM communicated to BSEE that the retainer ring's material yield strength value was increased. They noted that a closer match in yield strength values between the retainer ring and fasteners was a standard practice for other wing valve designs they manufacture. The new material yield strength value for the retainer ring was not provided by the OEM to BSEE. If the increase in material yield strength is not adequate, there is still a potential for hazardous failures if the fastener's threads are stripped from the retainer ring.

2) The amount of thread engagement between the fasteners and the retainer ring was noted. It appears there was additional space in the retainer ring for longer fasteners (which would have allowed more thread engagement). The OEM deemed that the chosen fasteners provided a "good" design safety factor with the length of thread engagement. Therefore, the OEM indicated that additional thread engagement of the fasteners into the retainer ring was not necessary for the anticipated operating loads of this wing valve design. The valve design should meet the API 6A Nineteenth Edition's thread engagement requirement to ensure that the equipment is fit for service.

WING VALVE INDUSTRY STANDARDS AND REGULATIONS

Two standards apply to the design of Christmas tree wing valve. These are:

- API 6A *"Specification for Wellhead and Christmas Tree Equipment"*; and
- API 17D *"Design and Operation of Subsea Production Systems-Subsea Wellhead and Tree Equipment"*

API 6A, Nineteenth Edition, is incorporated by reference into BSEE regulations in CFR *§250.806 Safety and pollution prevention equipment quality assurance requirements.*

Additionally, CFR §250.806 above also references high pressure high temperature (HPHT) equipment which includes threaded connections. Additional information regarding BSEE regulations, and these incorporated specifications can be seen in Appendix B.

At the time of this failure, API 17D, Second Edition, was not incorporated into BSEE's regulations. API 17D, Second Edition, was incorporated into BSEE regulations in the Blowout Preventer Systems and Well Control Rule (published in the Federal Register on April 29, 2016). The wing valve in this evaluation was designed to API 17D, First Edition. API 17D, First Edition, published in 1992, references API 6A for thread engagement requirements. In 1992, API 6A, Nineteenth Edition, was in effect. The following was required under Section 4, Bolting, of API 6A, Nineteenth Edition:

> "*Stud thread engagement length into the body shall be a minimum of one times the outside diameter of the stud.*"

This requirement for thread engagement has remained in each edition of API 6A, including the current (Twentieth) Edition. Likewise, API 17D has retained this thread engagement requirement in its second edition by explicitly stating the requirement (instead of referencing API 6A). Therefore, all editions of both API 6A (Nineteenth and Twentieth editions) and API 17D (First and Second Editions) mentioned in this report have the same thread engagement requirement of one times the outside diameter of the fastener.

The fasteners involved in this failure had an outside diameter of 0.875 inches and witness marks showing thread engagements ranging between 0.56 and 0.793 inches. The failure indicates that this wing valve's thread engagement did not meet the requirements of API 6A Nineteenth Edition, or API 17D First Edition. The OEM design provides for a minimum thread engagement of 0.875 inches into the retainer ring, however, during manufacturing the fastener was not threaded to this minimum thread engagement depth requirement. Following the failure, the OEM made design changes to the wing valve which included an increased material strength for the retainer rings, revised tolerances on the housing and clamp ring, and increased fastener length on the nut end. The OEM notified operators using this design wing valve about the failure during qualification testing.

The BSEE QC-FIT also requested additional information from the OEM regarding the specifics of the design changes made as a result of this failure. The OEM did not provide information about the new material properties for the retainer ring, revised tolerances for the housing and clamp ring, or the new fastener length. BSEE recommends that the OEM verify that the thread engagement matches the OEM design specification, and complies with API 6A Twentieth and 17D Second Editions requirements.

RECOMMENDATIONS

Design changes made by the OEM to the retainer ring's material properties reduced the risk of failures occurring in the future. However, the OEM may need to consider additional evaluation of the wing valve design to ensure adequate thread engagement into the retainer ring to further reduce potential failures.

In response to these findings, BSEE has the following recommendations

Recommendations specific to the horizontal subsea wing valve include:

1. The OEM should consider increasing the required amount of thread engagement into the retainer ring as specified in API 6A, Nineteenth Edition, and required per BSEE regulations in §250.806, to ensure proper closure bolting.

Recommendations applicable to wing valves, in general, include:

1. Industry should consider funding a joint-industry project to evaluate wing valve design, manufacturing processes, and material property requirements. This joint-industry project should include an analysis of optimal thread engagement, material properties, and load designs for wing valves.

2. Industry should evaluate wing valve designs to ensure the material properties (e.g. yield strength) closely match and acceptable stress levels are achieved. Retainer ring material properties should be compared to fastener material properties to ensure consistent load paths, adequate closure bolting, and verify that the valve is fit for service.

3. Industry should evaluate wing valve fastener thread engagement and interface tolerances to ensure proper closure bolting. Wing valve designs should provide adequate allowance for thread engagement and manufacturing procedures should be evaluated to verify proper thread engagement prior to qualification testing.

4. BSEE should require operators to provide supporting documentation detailing why a wing valve is not required to meet API 6A Nineteenth Edition or 17D Second edition for thread engagement as part of a production plan or Deep Water Operations Plan (DWOP).

ACRONYMS

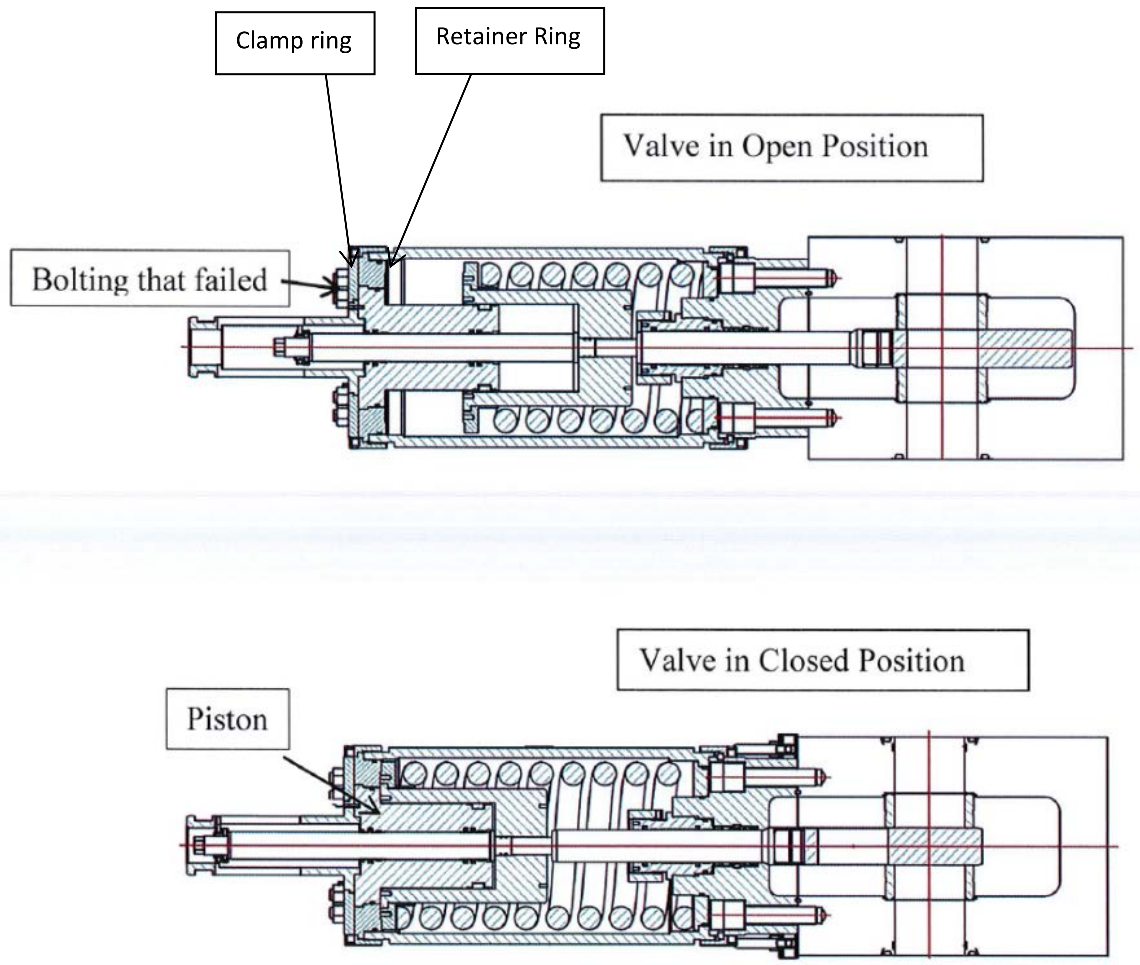
APD	Application for Permit to Drill
API	American Petroleum Institute
APM	Application for Permit to Modify
ANL	Argonne National Laboratory
ASME	American Society for Mechanical Engineers
ASTM	American Society for Testing Materials
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
DWOP	Deep Water Operations Plan
HPHT	High Pressure High Temperature
KSI	Kilopound per Square inch
OCS	Outer Continental Shelf
OEM	Original Equipment Manufacturer
PIB	Product Information Bulletin
PSI	Pounds per Square Inch
PSL	Product Specification Level
QA	Quality Assurance
QC	Quality Control
QC-FIT	Quality Control Failure Incident Team
RCA	Root Cause Analysis
SSSV	Sub-surface Safety Valve
YS	Yield Strength
UTS	Ultimate Tensile Strength

APPENDIX A

The evaluated wing valve consisted of the following primary components:

1. Housing
2. Retainer Ring
3. Clamp Ring
4. Nuts
5. Fasteners

The retainer ring fits into the housing, which has threaded holes where the fasteners engage at the bottom end. The clamp ring attaches to the end (top) of the housing with through holes, which allow the fasteners to pass through. The nuts are then screwed onto the fasteners, securing the clamp ring to the housing and simultaneously securing the retainer ring inside the housing. The figure below shows an enlarged schematic view of these components and the assembled view.



APPENDIX B

API 6A, Nineteenth Edition, is incorporated into BSEE regulations as the following:

§250.806 Safety and pollution prevention equipment quality assurance requirements.

(3) All SSV's and USV's must meet the technical specifications of API Spec 6A and 6AV1. All SSSVs must meet the technical specifications of API Specification 14A "Specification for Subsurface Safety Valve Equipment" (as incorporated by reference in §250.198). However, SSSVs and related equipment planned to be used in high pressure high temperature environments must meet the additional requirements set forth in §250.807.

CFR 250.806 above also references HPHT equipment (below), which includes threaded connections:

§250.807 Additional requirements for subsurface safety valves and related equipment installed in high pressure high temperature (HPHT) environments.

(a) If you plan to install SSSVs and related equipment in an HPHT environment, you must submit detailed information with your Application for Permit to Drill (APD), Application for Permit to Modify (APM), or Deepwater Operations Plan (DWOP) that demonstrates the SSSVs and related equipment are capable of performing in the applicable HPHT environment. Your detailed information must include the following:

(1) A discussion of the SSSVs' and related equipment's design verification analysis;

(2)A discussion of the SSSVs' and related equipment's design validation and functional testing process and procedures used; and

(3) An explanation of why the analysis, process, and procedures ensure that the SSSVs and related equipment are fit-for-service in the applicable HPHT environment.

(b) For this section, HPHT environment means when one or more of the following well conditions exist:

(1) The completion of the well requires completion equipment or well control equipment assigned a pressure rating greater than 15,000 psig or a temperature rating greater than 350 degrees Fahrenheit;

(2) The maximum anticipated surface pressure or shut-in tubing pressure is greater than 15,000 psig on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead; or

(3) The flowing temperature is equal to or greater than 350 degrees Fahrenheit on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead.

(c) For this section, related equipment includes wellheads, tubing heads, tubulars, packers, threaded connections, seals, seal, production trees, chokes, well control equipment, and any other equipment that will be exposed to the HPHT environment.