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HYPERBARIC PRESSURE TESTING OF A SUBSEA VALVE TO VALIDATE DEEP WATER CONDITION

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ABSTRACT

As exploration for new oil and gas sources goes deeper into the ocean and farther from shore, valves in service to that industry will have new pressure, temperature and durability requirements. Deep and ultra-deep prospects will continue to eclipse mature shallow water hydrocarbon production, which has seen a decline in capital expenditures in recent years. Thanks to major technological improvements and deepwater exploration and production successes, the definition of deep water have changed over the last decade passing from a threshold of 200 meters to over 1,000 meters.

What was considered deep 20 years ago is now considered shallow and the greatest potential is now represented by fields located at depths of over 1,000 meters? In fact, most new projects under development today range between 1,000 and 3,000 meters. These deeper water projects together with increased distances from shores and increasingly harsh environments represent the next frontier in exploration, production, and transmission. As far as valves, many new challenges in the high-pressure, high-temperature subsea environment exist, including the need to develop special alloys, coatings, elastomers, and thermoplastics that can withstand the rigors of ultra-deep operation.

This paper presents the modeling, simulation, pressure testing, and Hyperbaric testing of a subsea ball valve manufactured in Hawa Valves India Pvt. Ltd. A Hyperbaric chamber built to simulate pressure condition at a 3000m depth of water. Description of the test specimen is 2- inch ball valve test medium is water and nitrogen and the rated pressure is considered as per the ASME B16.34 and test medium of the hyperbaric test chamber is water. Design water depth pressure is considered as 330bar. Obtained results not only provided people with the access of understanding the hyperbaric pressure testing of subsea valves and also provide a brief understanding of thetesting procedure.

KEYWORDS: Hyperbaric Testing, CFD, Subsea Valves, Pressure, Ball Valve & API 6DSS

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Original Article

INTRODUCTION

Subsea valves face a unique challenge from even nuclear valves and land valves. Subsea valves desire to meet zero maintenance for the life of the valve. When you consider that true subsea valves must operate in water depths of thousands of meters, far from shore, where maintenance is simply not possible, you understand why the design and manufacture of these valves are unique [1]. With the above criteria in mind, the essential design and manufacturing characteristics of a subsea valve require precious selection of material, machining of components with close tolerances and careful pressure testing.

Materials that are corrosion resistant Alloy (CRA), verified and tested during the whole process with mechanical features that meet or exceed the limits of acceptability documented and traceable at the highest level.

Mechanical components created with the most advanced machine tools to achieve dimensional accuracy, tolerances, and repeatability considered unattainable only a few decades ago. Metal-to-metal seat-to-ball interface, dynamic sealing by hard coating such as HVOF (high-velocity oxygen fuel). This is a significant factor in the reliability analysis. Once assembled and tested, a subsea valve has to pass a second level of demanding gas tests ensuring both safe and reliable operation of the valve before it's placed in service [12].

Before a valve design based on the application is selected and used in the field, a valve prototype is submitted to a battery of tests that simulate the conditions the valve must withstand during the worst service situations and during the whole life of a valve in service. The valve must pass a combination of tests including pressure and temperature cycling, hyperbaric, endurance, and pipeline installation dynamics such as bending.

TYPES OF SUBSEA VALVE

There are two types of on-off valves traditionally used for subsea applications: the slab gate valve and ball valve are commonly used an on-off valve in a subsea application. Chokes are used as regulating valves. Slab gates are used mainly in the manifolds that collect the hydrocarbons from Christmas trees and transfer them to the flow lines. Slab gate valves in sizes up to 10 inches are preferable because they can be the most reliable in terms of sealing. They are also less sensitive to temperature variations. Slab gate valves can shut off a wellhead at the flow lines and are usually twinned for redundancy. Subsea slab gate valves are bubble tight, bidirectional and fully metal-to-metal sealing [2].

For severe service applications, the rising stem gate valve is preferred. Slab gate height increases significantly with size so ball valves are preferred for sizes above 10 inches. Ball valves are the sole solution for on-off service for the flow lines where temperatures and pressures decrease and for sizes above 12 inches. Different designs such as side entry, top entry, and fully welded ball valves are available to meet specific application requirements [12].

The main difference when comparing surface applications is extensive use of heavy cladding on sealing and crevice areas. In the subsea design, careful attention is paid to the bearing selection. Other common subsea features include scrapers and guides as well as metal-to-metal sealing. In some cases, check valves have been used as subsea isolation valves in very severe conditions such as those in the vertical position, under 10K of pressure and in depths of more than 2,000 meters. The check valve represents a relatively inexpensive, yet reliable control solution. Despite its design simplicity, prototype testing for check valves is no less stringent than for gate and ball valve pre-qualifications [4].

BALL VALVES IN SUBSEA

Ball valves have been used for many years in subsea applications. Downstream of the production Christmas trees, ball valves were first used on land with the development of the gas industry and gas pipeline valves. Up to that time, pipelines were liquid only and pipeline gate valves were the standard. Even today it is typical to see gate valves specified for liquid pipelines and ball valves specified for gas pipelines. Both configurations have significantly different requirements from the drilling and Christmas tree valves both in pressure and size [5].

There are deepwater applications for which ball valves can provide operational and cost advantages over gate valves. Improvements in non-metallic seals and coatings are raising the reliability of ball valves to the point where users are now specifying ball valves and their use is growing in deeper water depths [5].

LITERATURE SURVEY

Philip L. Skousen Revised to include details on the latest technologies, Valve Handbook, Third Edition, discusses design, performance, selection, operation, and application. This updated resource features a new chapter on the green technology currently employed by the valve industry, as well as an overview of the major environmental global standards that process plants are expected to meet. The book also contains new information on valves used in the wastewater industry, applying emergency shutoff (ESO) valves.

J. W. Hutchison, This publication was prepared under the direction of the final control elements committee of ISA's Process Measurement and Control Division. This handbook is intended to acquaint engineers with the factor of control valve design and application and to assist instrument engineers in the selection of the best valve body, actuator, and accessories of application.

ISO 13628-4, this part of ISO 13628 provides specifications for subsea wellheads, mudline wellheads, drill-through mudline wellheads and both vertical and horizontal subsea trees. It specifies the associated tooling necessary to handle, test and install the equipment. It also specifies the areas of design, material, welding, quality control (including factory acceptance testing), marking, storing and shipping for both individual sub-assemblies (used to build complete subsea tree assemblies) and complete subsea tree assemblies.

David R Mefford, in this paper mention of Deepwater subsea ball valves with the growing development of deep water oil and gas fields and the increasing need for the larger bore, higher pressure valves, a move to consider ball valves as another option to traditional gate valve solutions has been growing in popularity. With improvements in seals and materials, the reliability of ball valves has reached a point where they must be considered as viable options to gate valves in many subsea applications.

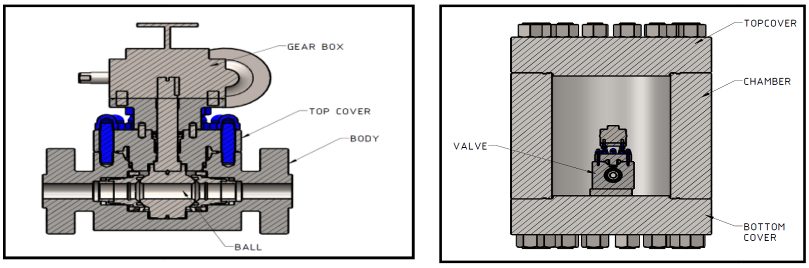
API 6DSS, this specification defines the requirement for the design, manufacturing, quality control, assembly, testing, and documentation of ball valve for application in subsea pipeline systems for the petroleum and natural gas industries.

API 6A, "Specification for wellhead and Christmas tree equipment" this international standard requirements and gives recommendations for the performance, dimensional and functional interchangeability, design material, testing, inspection, welding, marking, handling, storing, shipment, purchasing, repair and remanufacture of wellhead and Christmas tree equipment for use in the petroleum and natural gas industries.

API 6D, " Specification for pipeline and piping valves" this specification defines the requirements for the design, manufacturing, assembly, testing, and documentation of ball, check, gate, and plug valves for application in pipeline and piping systems for the petroleum and natural gas industries.

Rotork Gears, "Specifications for WGS Gear Boxes- Worm Gear Series are designed for heavy duty subsea applications at any depth with carefully chosen material to offer the highest level of reliability required in this very harsh environment.

METHODOLOGY



(a) (b)

Figure 1: (a) Ball Valve Nomenclature (DN50, CL2500)

(b) Hyperbaric Chamber Nomenclature

We designed a ball valve of size DN50xCL2500 and specifications of the valve is given in Table 1 and perform design calculations like torque, Stem diameter Flange thickness and bolting calculations, FEA analysis conducted to check the deformation by using ANSYS and manufactured as per the API6DSS standard.A vertical Hyperbaric chamber is installed as shown in Figure 1 (b) and the specification of the chamber is as shown in Table 2. And hyperbaric pressure testing is conducted to simulate the deep water condition.

Table 1: Key Specifications of Valve

Valve Type	Top Entry Trunnion Mounted Ball Valve
Valve Size	2” (DN50)
Valve Class	2500#
Design Standard	API 6DSS 2nd Edition Dec2009/ISO 14723-2009
Body Material	ASTM A 182 Grade F51

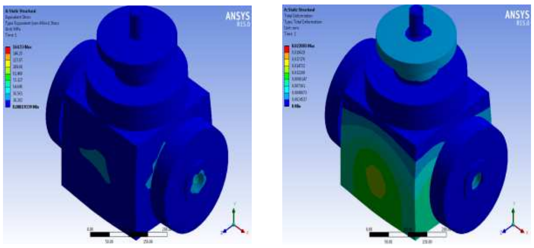
Table 2: Key Specifications of Hyperbaric Chamber

Type	Hydrostatic
Test Medium	Water
Test Temperature	5°C±4°C
Test Depth	3000 m
Test Pressure	330 bar
Chamber pressure capacity	380 bar

BALL VALVE NUMERICAL SIMULATION

A three- dimensional geometry was developed by using Solidworks to facilitate further changes to the geometry. We conducted a structural analysis of the valve by using ANSYS we divided these structural analyses in 3 cases ie., analysis with respect to internal pressure, External Pressure and combined effect of internal and external. Based on the below results in figure 2,3,4 Stresses and deformation is within allowable limit hence the design is safe.

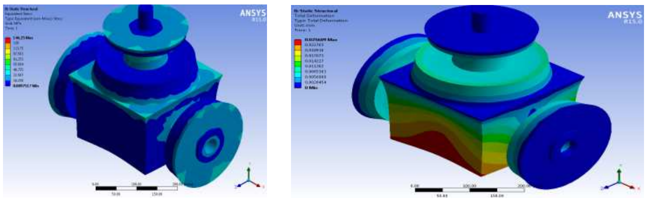
Case 1: Internal Pressure Only



(a) Equivalent Stress in Valve (b) Total Deformations

Figure 2: Internal Pressure Static Analysis

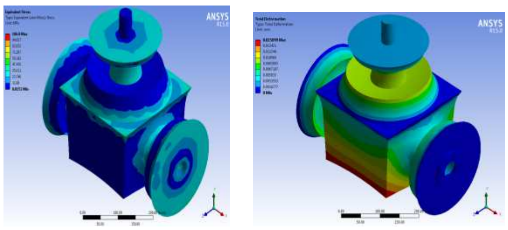
Case 2: External Pressure Only



(a) Equivalent Stress in Valve (b) Total deformations

Figure 3: External Pressure Static Analysis

Case 3: Combined Internal & External Pressure



(a) Equivalent Stress in Valve (b) Total deformations

Figure 4: Internal & External Pressure Static Analysis

WHAT IS HYDROSTATIC TESTING?

Hydrostatic testing is the most common procedure used to qualify newly manufactured cylinders, spheres, and tubes used for the transportation of dangerous goods. Hydrostatic testing is also required periodically to re-qualify these pressure vessels for continued service. During a hydrostatic test, a pressure vessel is placed inside a closed system, usually a test jacket filled with water, and a specified internal water pressure is applied to the container inside this closed system. The applied internal pressure causes an expansion of the container being tested, and the total and permanent expansions that the container undergoes are measured. This volumetric expansion measurement, in conjunction with an internal and external visual inspection of the container, is used to determine if a pressure vessel is safe for continued use, or has suffered from a degradation in its structural integrity and must be condemned.

Some pressure vessels may be re-qualified by means of a proof-pressure test. This method, also known as a modified hydrostatic test, consists of subjecting a pressure vessel to a specified internal pressure and inspecting the pressurized container for leaks, bulges or other defects.

For pressure-controlling equipment, as defined by API 6A and API 17D, external pressure (or in some case, backpressure) may not always be present downstream of the pressure-controlling element (closure mechanism), or the backpressure pressure magnitude may fluctuate. Example of this scenario is a closed valve or choke where the downstream pressure of the closure mechanism may not always be equal to external ambient seawater pressure (e.g., a subsea flow line is blown-down to low pressure during a system shut-in to avoid hydrate formation in the flow line as its contents cool down).

TEST DESCRIPTION CASE WISE

Case A: Hydrostatic Shell Test (Water)

In this case, hydrostatic shell test is conducted on the valve by using water as medium Pressurizing the valve with a valve in half open position and hold for 120 minutes and visually examined for external leakage thru body seals, drain or vent external connections. Initially, pressure is climbed to 646 Bar and the same pressure is maintained for 120 minutes and then depressurized the valve. There is no external visible leakages are observed hence the test is accepted. Operational test is conducted to measure the maximum torque required to operate the valve for the open and close with bore pressurized and the cavity at atmospheric pressure, closed to open with both sides of the obturator pressurized and the cavity at atmospheric pressure and with one side pressurized and the results are as shown in Figure 5.

Figure 5: Machine Generated Graph of Hydrostatic Shell Test

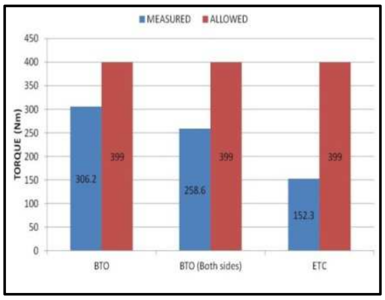


Figure 6: Torque Measured and Allowed

Case B: Gas Shell and Seat Test (Nitrogen Gas)

In this case, gas test is conducted on the valve by using nitrogen gas as a medium and the procedure is as per case A. No visible external leakage, hence the test is accepted.

Unless the test is performed using nitrogen with helium traces measured using a mass spectrometer, a maximum of 0.27ml/min is allowed from any leak path.

Table 3: Gas Pressure Testing (Medium – Nitrogen Gas) (Testing as Design Temperature)

Test	Pressure (Bar)	Duration	Results	Ambient Temp
Shell	474	300 seconds	Accepted	37°C
Seat	474	300 seconds	Accepted	37°C

Case C: Hydrostatic Seat test (Water)

In this case, hydrostatic seat test is conducted on the valve by pressurizing the valve with the valve is in a closed position and hold for 10 minutes pressure is noted as 474 bars shown in figure 7and leak measured of a valve seat and open the valve under differential pressure and depressurize the valve. No visible leakage is observed (leakage rate for soft seated shall not exceed ISO 5208, Rate A) hence the hydrostatic seat test is accepted.

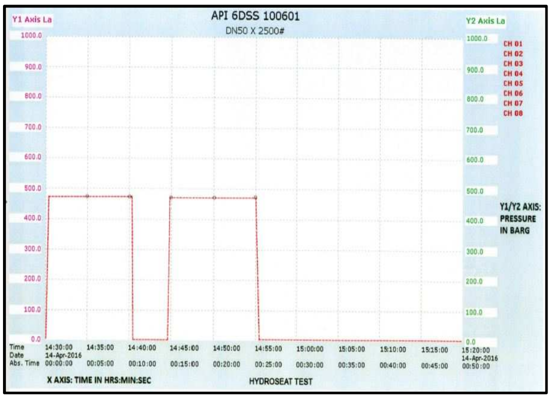


Figure 7: Machine Generated Graph of Hydrostatic Seat Test

Case D: Pressure Testing of Valve inside the Hyperbaric Chamber

In this case, valve is installed inside the hyperbaric chamber and connection checked for leakages. Pressurized the hyperbaric chamber to 1.1 times the design water depth pressure and stabilize the pressure and maintain the hyperbaric pressure through-out the test. The pressure in hyperbaric chamber shall be constant throughout the test.

(a) **(b)**

Figure 8: Machine Generated Graph of Hyperbaric Seat Test

(a) **(b)**

Figure 9: Machine Generated Graph of Hyperbaric Seat Test

Case E: Shell and Seat test using Nitrogen under Continuous External Hyperbaric Pressure

In this case the gas shell test of valve conducted in this pressurized with a valve in half open position at specific test pressure and holds for 120 minutes and isolates the valve from the pressure source meanwhile check for pressure drop to identify for any external leakages from the valve body. And depressurized the valve no pressure drop is allowed during the shell test. And the same test repeated with the valve in a closed position. For seat test pressurized the valve with the valve in closed position at specified test pressure and hold for 15 minutes and isolate the valve from the pressure source. Check pressure drop to identify for any leakages from the valve seat, operate the valve from fully closed position to fully open position under differential pressure and depressurized the valve and repeat the operation for another side of the valve. No pressure drop is observed during seat test hence test is accepted.

Case F: Vacuum Shell Test of Valve Under Continuous External Hyperbaric Pressure

In this case, create a vacuum in the test valve with the valve in half open position and apply a vacuum of 5 millibars, and isolate valves from the vacuum pump and hold the vacuum for the duration of 120 minutes. While test duration checks the vacuum gauge for any drop in vacuum and after test release the vacuum. No vacuum drop is observed during test hence test is accepted.

Case G: Cyclic Testing of Valve Using Nitrogen Gas Under Continuous External Hyperbaric Pressure

In this case pressurized the valve with the valve is closed position at rated pressure and operated the valve from fully closed position to fully open position under differential pressures, with bore pressure vented to atmospheric and depressurized the valve. Repeat the same procedure for 100 times for another side "A" of the test valve and for side "B".

RESULTS & DISCUSSIONS

Figure 10 shows the experimental setup of hyperbaric test located in Hawa Valves India Pvt. Ltd. From Below results, the valve has successfully passed the hyperbaric testing requirements of the standards API 6DSS. The valve was tested under hyperbaric conditions up to 3000m water depth external pressure of 330 bars and 200 cyclic testing were conducted, with shell test, seat test, and vacuum test, and verified that the external hyperbaric pressure testing at depth is of no consequences to the valve, while the valve is under no internal pressure.

The valve was disassembled after the completion of type test and the valve components were visually examined for any wear and tear and any other visible damages on the shaft and sealing area. There was no wear and any other significant defeats observed.

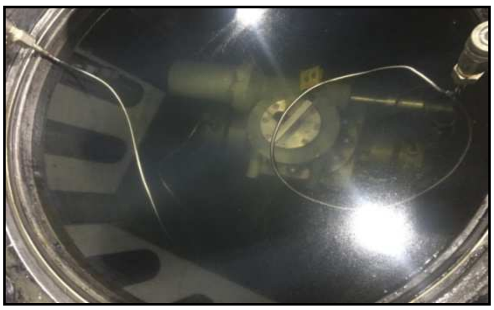


Figure 10: Experimental Setup of Hyperbaric Pressure Test @ (Hawa Valves India Pvt. Ltd)

Table 4: Test Results

Test stage	Test Medium	Pressure (Bar)	Test Duration (minutes)	Measured	Results
Shell Test	Water	648	120	No visible leakage	Satisfactory
Torque test	Water	431	120	No leakage	Satisfactory
Seat test (side a)	Water	474	10	No leakage	Satisfactory
Seat test (side b)	Water	474	10	No leakage	Satisfactory
High Pressure Gas Shell Test	Nitrogen	474	120	No leakage	Satisfactory
High Pressure Gas Seat Test (side A)	Nitrogen	474	10	No leakage	Satisfactory
High Pressure Gas Seat Test (Side B)	Nitrogen	474	10	No leakage	Satisfactory

Table 5: Hyperbaric Testing of Valve Under External Pressure

Test stage	Test Medium	Pressure (Bar)	Test Duration (minutes)	Measured	Results
Pressurized Hyperbaric Chamber	Water	120	*	No visible leakage	Satisfactory
Shell test	Nitrogen	431	120	No leakage	Satisfactory
Seat test (side a)	Nitrogen	474	10	No leakage	Satisfactory
Seat test (side b)	Nitrogen	474	10	No leakage	Satisfactory
Vacuum Shell test	Vacuum	474	120	No leakage	Satisfactory
Cyclic Test (100 times) side A	Nitrogen	474	*	No leakage	Satisfactory
Cyclic Test (100 times) side B	Nitrogen	474	*	No leakage	Satisfactory

Table 6: Test Results

Test stage	Test Medium	Pressure (Bar)	Test Duration (minutes)	Measured	Results
Shell test	Nitrogen	474	120	No Pressure Drop	Satisfactory
Seat test (side a)	Nitrogen	474	10	No Pressure Drop	Satisfactory
Seat test (side b)	Nitrogen	474	10	No Pressure Drop	Satisfactory
Vacuum Shell test	Vacuum	-0.5	10	No Vaccum drop	Satisfactory

Table 7: Pressure Testing of Valve Post Hyperbaric Test

Test stage	Test Medium	Pressure (Bar)	Test Duration (Minutes)	Measured	Results
Shell test	Water	648	120	No Leakage	Satisfactory
Seat test (side a)	Water	475	10	No Leakage	Satisfactory
Seat test (side b)	Water	475	10	No Leakage	Satisfactory

CONCLUSIONS

This paper has provided an experimental investigation of the Hyperbaric pressure Test on a Ball valve, includingmodeling and the simulation of the Ball valves. The experimental results shows positive outcome and the valve wasdisassembled after the completion of type test and the valve components were visually examined for any wear and tear and any other visible damages on shaft and sealing area. There was no wear and any other significant defeats observed hence theexperimental is successful.

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ABOUT COMPANY

Hawa Valves are manufacturers and exporters of valves for application in critical hydrocarbon/oil and gas upstream, midstream, downstream, chemical, power, marine, mining and general industry. Hawa Valves have ISO 9001. ISO 14000, OHSAS 18000, SIL 3, CE/PED, ATEX certified and have American Petroleum Institute monogram licenses of API 600, API 6A, API 6D, API 6DSS and API 609.

The dedicated in- house R&D facility is recognized by Government of India, Ministry of Science and Technology, Department of Scientific and Industrial Research. Hawa Valves hold international patents.

"Hawa Valves India Pvt. Ltd. As a company is ready to meet all valves needs in any environment or filed" Likewise, through a whole array of accomplishment ,including our vision, enthusiasm, flexibility, innovative product development and use of technology diversity of exports, emphasis on quality and shrewd business acumen indeed seems assured of a very bright future.

For more details: http://www.hawavalves.com/

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Author Profile

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Currently R&D Head and Chief Technical Officer of Hawa Valves, has over 28 years' experience in valve industry. Leading R & D and Technical departments, develop new product range, develop new equipment for various validation testing as per valve industry norms, upgrade existing equipment in line with latest industry updates, provide technical guidance, implement latest technologies in product developments, mentoring in skill development, participate in technical events worldwide, evaluate and resolve technical feasibility, visit end user sites such as offshore platforms, impart technical training to staff. Assist in developing new dies, fixtures, tooling and processes. Assist in developing latest machineries and equipment required for product development

Khalid Ansari

M. Tech in Machine Design and having 3.5 years' experience, currently Engineer in R&D Department of Hawa Valves India Pvt. Ltd

JVS Praveen

Received M. Tech Degree in Computer aided Design and Computer aided manufacturing (CAD/CAM) from Gayatri Vidhya Parishad College of Engineering in 2013. Having 3.5 years of experience and Currently working as a Jr. Design Engineer (R&D Department) in Hawa Valves (India) pvt. Ltd