Advances and Impact of Software-Based Deepwater Blow Out Preventer Testing
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Abstract

To advance the technology of BOP leak detection through a software development initiative, operators, service providers, and drilling contractors established an industry consortium in early 2009. The initial development focused on the testing of BOPs in deepwater. Upon completion of the pilot program on five deepwater rigs, the results exceeded original expectations. The test results proved the software was effective, efficient, and rig friendly. Once a test plan was constructed, with the click of the “Start” button, the software was completely automated, up to the time of printing the report.

Through an iterative and collaborative process, a unique solution for the Low Pressure (LP) and High Pressure (HP) BOP testing has been developed. For example, due to the constraints and subjective nature of the current Circular Chart Recorder (CCR) methodology for validating a test, a small leak may not be identified for up to 30 minutes into the HP test. With this new methodology, objective identification of a slow leak typically occurs during the LP portion of the test in less than three minutes; and a good test (no leak) typically validates in the regulatory agency’s minimum holding time requirements. Additionally, the software provides greater assurances, transparency, and reliability as compared to the CCR. The antiquated CCR is easily manipulated in multiple ways, which is eliminated with this solution.

This software provides the industry with a tool for objective, efficient test validation. The software generates simple, clear, concise reports and contains more information as compared to what is currently available. It archives tests in a secure format, and the software allows the users to retrieve and review the tests for any required scrutiny. It also prints the reports to a secured PDF format and archives them.

This paper discusses the current state of the development along with the associated benefits. A vision of the application development pipeline for further pressure analysis opportunities is also introduced.

Introduction

The oil and gas industry has advanced very little with respect to pressure testing critical equipment on drilling rigs. As the industry moves into operating in deeper water and uses non-water-based fluids, the challenges associated with obtaining effective pressure tests continue to grow.

Historically, digital pressure measurement solutions had not been considered due to its accuracy. Prevailing interpretations of regulatory requirements to “hold pressure” were to demonstrate a flat-line on a pressure chart for a specified period of time. With the relatively low resolution of a CCR device, a flat-line was essentially produced when the resolution of the device was exceeded (typically 4-6 PSI). Analog chart recorders had the additional “benefit” of allowing excessive damping and manipulation without recording such settings or actions.
The accuracy of digital solutions showed that pressure typically decayed for a long period of time, requiring an excessive amount of time to stabilize and “flatten” for the required holding time. This pressure decay was a result of thermal influences as documented by Franklin, Vargo, Sathuvali, and Payne (2004).

The industry consortium acknowledged that the CCR, a piece of technology over 100 years old, needed to be replaced with a smarter Best Available Safety Technology digital solution. They formed a project to develop a new methodology to identify leaks more efficiently, accurately, and consistently. It was acknowledged that the solution must utilize digital accuracy and implement an analysis methodology that would take into consideration the scientific cause of pressure decay and would use this information constructively in test analysis and system verification.

**Joint Industry Project (JIP) Cooperation**

During 2009 and 2010, four operators, along with the support of several service providers and drilling contractors, participated in a JIP. As the main goal, the consortium wanted to develop state of the art leak detection with best practices for testing BOPs in deepwater. The JIP was broken into two phases.

Phase I gathered digital data from BOP tests performed in the Gulf of Mexico (GoM) and around the world. Archived data was used as test data and a library of over 100 data sets was built. Review of the test results showed that each data set had from between 10 to 25 tests, 86% of which represented passing tests.

In the course of data analysis, it was interesting to observe the significant variability in which a test was conducted and validated. There was no consistency or set standard for validating a test. With respect to the psi per minute pressure change during the last five minutes of a test, commonly referred to as the flat-line, the range was from 4 to over 20 psi/min.

The data archives provided insight into an automated approach for validating deepwater BOP pressure tests. A software prototype was developed along with workflow automation features, which was refined through multiple design review meetings with the JIP members and the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE). During these meetings, the value of the proposed solution from both the JIP members and the BOEMRE was established and the excitement to perform field validation grew. In preparation for field trials, the prototype software was further enhanced by building in connectivity, an enhanced user interface for workflow management, and comprehensive reporting capability. Phase I was completed when the software was ready for field trials.

Phase II field trial installations commenced on five deepwater rigs in the GoM. The software was also run in the background in a Real Time Operation Center during BOP and Manifold testing from multiple rig types (deepwater, TLP, and jack-up). The goal of Phase II was to validate and work out software issues, including obtaining feedback from the end users for optimizing the value and ease of use of the software package.

During Phase II, the software operations manual was developed along with the formal leak detection certification training. A comprehensive submittal document was prepared, which chronicled the application development activities and included a risk assessment. Phase II was completed when the JIP members and the BOEMRE approved the technology for use.

The scope of the development expanded during Phase II. Rig personnel recognized the value and were requesting utilization of the software for Stump Testing the BOP. Additional suggestions for use of the software in other leak detection activities were received from other parties. As a result, the stump test solution, function test recording, and enhanced reporting were also added to the development.

Even with the JIP officially complete, the group is still effectively working together in the natural progression of the development. A roadmap of future capabilities has evolved for tracking and prioritizing the suggestions. The associated assurances are spreading to other applications, such as accommodating formation integrity, casing, negative in-flow, and other pressure tests.

**Development of Leak Detection Methodology**

**Leak Detection Basics**

Although the term “pressure test” is commonly used in the industry, the actual meaning behind this phrase is leak detection by pressurization, containment, and analysis. The analysis steps in leak detection are ostensibly quite simple:

1. Establish the criteria for a valid test.
2. Evaluate data to determine whether the criteria are met.
3. Provide notification of test result; i.e. a passing test (no leak) or a failed test (detected leak).

However, in deepwater operations with complex influences on the contained system, analysis is not a simple exercise. To deal with the challenges faced in deepwater operations, an analysis methodology has been developed for leak detection testing. Additionally, to ensure the methodology is safe and effective, a risk assessment has been performed on the methodology.

**Analysis Methodology**

A comparative conformance algorithm was developed as the criterion evaluation methodology, where a benchmark thermal response for a system series of tests is first conducted. The benchmark is held to a predetermined standard (criterion) for a valid test. Frequently, the benchmark is a test that can be conducted out of the critical path of operations.

For subsequent tests in the system after the benchmark test, the comparative algorithm is utilized for validating a test. The conformance algorithm detects a leak typically within a few minutes, a very small fraction of the time it takes to detect a leak with a CCR.

**Risk Assessment**

During the initial phase of the development, a great amount of attention was given to understand the potential for an incorrect evaluation of a test, as per the matrix \( \text{Fig. 1} \). With a thorough understanding of the thermal influences on a test, the question was asked: “What potential is there for a small leak to be reported as a passing test (the software fails to detect the leak)?” With the benchmark methodology in place and after extensive evaluation, it was determined that the risk was low, as a very unnatural thermal response captured by the benchmark test needs to take place in order to mask a small leak on subsequent tests.

**Fig. 1–Impact of software result compared to actual condition matrix.**

<table>
<thead>
<tr>
<th>Actual Condition</th>
<th>No Leak</th>
<th>Leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Determination</td>
<td>No Leak</td>
<td>Good (True Positive)</td>
</tr>
<tr>
<td></td>
<td>Leak</td>
<td>Bad (False Positive)</td>
</tr>
</tbody>
</table>

A result of the comparative conformance algorithm is that if there is a small leak during the benchmark test, all subsequent tests will fail, which will raise an obvious red flag during the testing process. Also, because a set of tests conforms one to another, there is built in verification, as the sum of the tests validates the individual tests.

**Data Sets and Transform Development**

The library of data sets provided a sufficient amount of scenario data on which to work, enabling the comparative transform and set of procedures to be developed. The transform, a comparative algorithm, relates to a known good benchmark test, and the transform is proven to amplify a data outlier (a leak) allowing for an objective test validation in a matter of minutes.

Fundamentally, there are two potential components to pressure decay. The first decay component is due to a complex set of thermal influences. The second component is a leak. The combination of these two components equals the total pressure decay, of which, the leak component is equal to zero most of the time; i.e. a “good” test validating equipment integrity.
The comparative transform deconvolves the leak component and amplifies it for identification as a failed test. Algorithms are used in image analysis and signal processing will not exist without transforms. A transform allows one to process raw data and present a comparison that reveals what is not otherwise detected.

As the transform was iteratively developed, the criteria for identifying leaks were tested and fine-tuned. With over 2,000 tests, the development was robustly tested and validated on archived and real-time tests.

Through analyzing the data sets, the following observations were made:

1. Understanding system response requires consideration of the context of the leak test with respect to the fluids, pressure, and volume of the system.
2. Inconsistency in test execution procedures creates ambiguity; consistency in procedures provides clarity.
3. Combining consideration of context with test procedure consistency is a key factor in effective leak detection.

These points must be addressed thoroughly in training and education to maximize the effectiveness of the leak detection methodology.

**Software Demonstration and Field Leak Simulation**

The introduction of any new tool, whether it is mechanical in nature or software, is going to be met with skepticism in the field. It is very common to hear phrases, along the lines of, “we have done it this way forever, why do we need something new?”, or “that will never work”, etc. Well documented factors leading to human resistance to change, as determined by Schuler (2003), include a natural skepticism until a change is proven, fear of lack of competence to deal with a change, fear of hidden agendas, and change perceived as reducing one’s authority or importance.

Training and demonstration provided the ability to convert the skeptic into an advocate by showing that the product was truly viable. The training proved to be critical, as it provided the basis for understanding the development and increased comfort and confidence with the application. The goals stated in training were to create a safer, more efficient verification of BOP equipment. This made the purpose and agenda of the application very clear, particularly in light of newly emphasized importance on BOP equipment verification following the 20 April 2010 GoM Macondo incident. Also, any importance previously placed on subjectively interpreting a paper chart was likely to be less desirable after understanding the application and its benefits.

Once training was completed, an actual leak demonstration on the rig was often another step for validating the new tool, as performed in the following scenario. The rig was operating in 5,300 ft of water. Three 5,000-psi tests were performed down the choke line against closed fail-safe valves at the BOP. The software ran as though conducting an actual test sequence with all participants involved. The first test was conducted as the benchmark test. The second test was validated in five minutes. Once the third test was validated as a non-leaking test, a leak was initiated at the choke manifold. Out of the total system volume of 105 barrels, less than 6 oz (half of a coke can) was bled back when the software confirmed a leak. With this demonstration, the rig personnel were convinced this was a better tool, as the leak was not detected on the CCR.

**Evolution of Application and Program Development**

**Software Application Development and Influences**

Modern Cement Units (CU) typically provide instrumentation and measurements for pressure, rate, and volume. Such data is readily available from CU system control apparatus in an easily usable form (delimited text or WITS standard formats). Because the CU is used to create the pressure for BOP and Manifold tests, this data availability has enabled the development and implementation of a software-based solution.

The analysis components developed during Phase I of the JIP were embedded into an application where user interaction, ease of use, workflow management, and presentation of results were carefully considered and implemented. Parameters controlling the digital analysis and passing criteria for all tests defaulted to values consistent with prevailing US Code of Federal Regulations (2009).

Refinements made to the application throughout the initial adoption period included report enhancements, documentation of failed LP tests, the recording and reporting of BOP functional tests, and the introduction of pressure only tests for BOP stump tests.
Leak Detection Training and Education Opportunity

The foregoing analysis of data lead to a wealth of BOP testing facts and information, including:

- Further understanding of pressure increasing during the LP test.
- Additional analysis and understanding of HP test pressure response.
- Understanding the pressure variation response due to inconsistent pressuring methods.
- The real (negative) impact of “bumping” pressure during a test.
- The impact of fluid circulation.
- The correlation of pressure changes between systems under test.
- The limitations and issues related to the CCR.

This information was organized and used to develop the industry’s first in-depth training on BOP leak detection fundamentals, techniques, procedures, and best practices. The benefits of this education included increased safety and awareness, improved problem detection and isolation skills, and greater overall testing efficiency.

Software Features

Rig and Well-site data capture

The application allows critical Rig and Well-site information to be captured and retained for all tests at the site. This information is included in each test report.

Workflow Management

BOP test procedures are set up and retained for all tests and include the test description, required pressures, and benchmark group. Once tests are underway, the application automatically follows the test sequence, requiring interaction only to change sequence, add comments, or to pause or complete the test. Fig. 2 provides a view of the workflow configuration screen.

Fig. 2–Workflow configuration screen.
Ease of use

A great deal of attention and design has been placed on user interface and interaction of the application. Fig. 3 illustrates the clean design and intuitive organization of the application components, which are presented during a test. Fig. 4 shows the clear presentation of a failed LP input form.

Fig. 3—HP test and software user interface.

Fig. 4—Failed LP test corrective action screen.

1. Connectivity status
2. BOP test plan and current test executing
3. A pressure summary, test designator, and result indicator
4. A detailed pressure chart
5. An analysis and determination graph
6. Pressure and Time information
7. Test controls for Pause and Stop
Meaningful Results

The application produces test results that are logically organized, enable quick identification of results, and provide detailed information on each test including test progression, comments explaining results and a clear depiction of pressure, rate, and volume for each test. A final set of charts depicts pressure in a presentation similar to a CCR but with rate and volume information, automatic test designators, and a full history of events. See Figs. 5-7 for sample pages depicting test results.

Fig. 5–BOP test summary results.
Fig. 6–BOP test individual test result.
Connectivity and Communication

The application currently supports serial (RS-232) and network-based connectivity for its data feed.

The application is a well-behaved Windows-based application and is easily deployed on Windows-based computers, laptops, or virtual machines. Remote monitoring through terminal service applications (Remote Desktop, VNC, Citrix solutions) has successfully been used for remote operation, support, and monitoring.
Ensures regulatory compliance

The application provides workflow, test requirements, and documentation to support regulatory compliance of the US Code of Federal Regulations (2009) through:

- Documentation of the intended test plan and sequence.
- Guided completion of the test plan.
- Documentation of comments and action taken for failed test attempts.
- Full recording of the pressure, rate, and volume history of the entire test on a digital chart.
- Parameters control of the objective measurement and criteria of test pressures and hold-time durations.
- Passing of LP tests before HP analysis will be performed for each test.

Test archive and retrieval

All tests are stored in binary and PDF file formats and are protected by tamper-proof signatures and certificates. All local test history is available for review and further scrutiny. Test files are easily transported or replicated, and any installed version of the application can be used to retrieve and review test results.

Leak simulation and case histories (leak simulator)

The application was subjected to thorough testing of existing test data, as well as engineered test scenarios. A tool was developed to create test simulations to ensure broad coverage of all anticipated scenarios of pressure decay, noise, and leak rates. See Fig. 8 for an example of the data and leak simulator tool.

Fig. 8–Data and leak simulation tool.
Future Software Features

The application continues to evolve into an advanced pressure testing tool that replaces manual and/or CCR-based procedures.

One suggestion was to include the ability to document BOP valve diagrams and associate valve states (open or closed) and corresponding pressure and leak paths with individual BOP tests. Properly planned and documented test plans are critical to efficient and comprehensive component tests. Clear documentation of test plans ensures test execution is properly followed and confirmed, as well as providing clear results for oversight verification. In practice, a great deal of variability existed in producing these documents, component graphic representation, flow path, and component coverage reporting. Such variability and lack of standards needed to be addressed.

As a result, the software application is evolving to include the capability to represent graphically a rig’s BOP, manifold and test fixtures in a standard and consistent presentation or schematic. Test technicians can reference each test in a sequence to the schematic and include the valve alignment (open/closed status) as part of the test plan. With this information, the application can depict the intended pressure and leak path for each test step, providing a clear and consistent schematic along with the components tested for each step. See Fig. 9 for a schematic and pressure/leak flow example.

Fig. 9–Schematic and pressure/leak flow

Going forward, further development accommodating other pressure tests such as formation integrity, casing, negative in-flow and other tests is anticipated.
Summary and Technology Benefits

The following benefits were recognized because of the tests and participation:

- Objective leak detection – it was very difficult to detect small leaks on a CCR.
- Objective test validation – user no longer had to guess at the subjective flat-line.
- Eliminated the need for frequent re-testing due to the subjective evaluation (or false negatives).
- Majority of leaks are now identified during the LP test.
- Digital archival of all aspects of the tests.
- Volume record helped validate pressure test paths were properly lined up.
- Less exposure time for personnel and equipment to HP conditions increased safety.
- Real-time monitoring capability was provided.
- Test results cannot be manipulated.
- Ability to scrutinize tests, including pump data was provided.
- Reports were simple and clear in either PDF or IPT format.
- Leak detection and software competency training was provided – a first in the industry.

Conclusions

BOP leak detection tools and procedures based on thermal transforms and automated analysis improve leak detection accuracy and remove ambiguity and subjectivity from test result determination in field trials and production tests. BOP leak detection education and training increases operator knowledge and improve pressure testing procedures in efficiency, analysis, and problem determination.

The net impact of these improvements is safer BOP testing practices, more accurate results, more comprehensive test reporting and greater assurances and transparency.

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References

