Online Valve Monitoring Helps Shell Achieve Goals at the Ormen Lange Gas Plant in Norway

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Abstract

Located on Nyhamna Island on the west coast of Norway the Ormen Lange Gas Plant is the source of 20% of the natural gas imported into the United Kingdom. The gas is transported via the Langeled subsea pipeline across the North Sea from Nyhamna to the Easington Gas Terminal near the mouth of the River Humber on the UK's East coast. A/S Norske Shell operates and maintains the Ormen Lange plant.

Ormen Lange is one of the world's most advanced gas processing plants but is operated by a skeleton crew. In fact, Shell's goal for the facility is to operate and maintain the plant with as few people as possible. In order to accomplish this, online condition monitoring systems are employed to monitor virtually everything that moves in the plant including pumps and compressors, control valves, certain structures and critical shutdown isolation valves. A stated goal for the plant is that 70% of the maintenance budget and maintenance spending should be based on the results of condition monitoring. This lofty goal carries some element of risk since critical components cannot be allowed to run to failure. Any disruption in supply from Ormen Lange during the winter months causes significant perturbations in the gas markets and affects prices across Europe. Therefore, equipment condition must be accurately reflected by the monitoring systems and maintenance performed at the moment it is needed.

This paper shall discuss the condition monitoring approach for the 41 most critical shutdown isolation valves at Ormen Lange. The population of critical valves includes a mix of single and double acting pneumatic and hydraulic gate, ball and flow control valves. These valves are instrumented with strain gages, pressure transducers and acoustic leakage sensors. The sensor data is continually streamed to a data acquisition system that combines other important data pulled from the plant's distributed control system (DCS) such as command signals, limit switch signals and upstream and downstream system pressures to create a complete picture of what is occurring at the valve during operation. Acceptance criteria for key parameters such as thrust or torque output at various points in the cycle, stroke time, leakage and other critical measures are automatically evaluated by the valve monitoring system after each cycle and icons in the system display software provide a visual indication of current valve condition.

The monitoring approach is essentially the same as having a motor-operated valve (MOV) or air operated control valve (AOV) diagnostic system continually attached to these valves at all times. In our nuclear plant world the

analysis is akin to evaluating GL 89-10 data every time a valve cycles, in effect, allowing the valve to test itself and call someone when something changes for the worse. Score Atlanta has been assisting Shell in evaluating the on line results and performance of these critical valves for the past 3 years. The data is accessed with the right permissions from computers on the Shell network or remotely through the internet and the normal valve signature analysis process is used where needed to evaluate condition. The approach taken at Ormen Lange illustrates how industries around the globe are leveraging the lessons learned from 25 plus years of valve testing in the nuclear power industry by adopting systems that make valve diagnostics and condition monitoring a permanent and critical element of safe operations and effective plant maintenance.

Background

Following the introduction of the early MOV and AOV diagnostic systems in the mid-80s, the effectiveness and benefits of valve condition monitoring and signature analysis were widely discussed in industry forums such as the ASME-NRC Pump and Valve Symposium, various EPRI Valve Symposiums, MOV and AOV Users Group meetings and at other nuclear industry conferences. The early success of diagnostic systems for valves has also been well chronicled in numerous industry publications and a wealth of information is available on the internet for those seeking information on valve diagnostics and condition monitoring. The ASME code committees have also made adjustments to the various codes and code cases to get the most out of valve diagnostic and signature analysis techniques used as alternative methods for in-service testing of valves in nuclear power plants.

The leading valve diagnostic system and service suppliers have also marketed every process industry in every corner of the globe where improved valve performance is desirable. Because of the high cost and absence of regulatory pressure, adoption of valve diagnostics has not been as wide spread in other industries when compared to nuclear. However, that trend is changing at a fast pace. The move toward valve diagnostics and condition monitoring has moved fastest in the offshore oil & gas industry on the Norwegian side of the North Sea.

The initial adoption of valve diagnostics for the most critical valves on offshore platforms by Norwegian oil companies was not initially encouraged by the Norwegian Petroleum Directorate which is responsible for offshore regulatory compliance. However, after several years of experience with on line data acquisition and analysis, the current expectation among operators is that critical valves must be monitored at some level.

By 2003, at least a dozen Norwegian offshore platforms were monitoring critical isolation valves with on line monitoring systems. Strain gages, hydraulic and pneumatic pressure transducers and acoustic leakage detection sensors were producing a new level of confidence in valve performance. About this same time engineers designing systems and components and planning maintenance and operating strategies for the Ormen

Lange gas plant were searching for industry best practices related to valves.

In addition to valves, Ormen Lange has become synonymous with best practices in all areas of offshore oil and gas production. The gas field itself lies offshore and approximately 75 miles northwest of Kristiansund where the seabed is approximately 3,300 feet below the surface. There is no platform or other vessel on the surface above the wells as would normally be expected. The wells are completed subsea and the gas is piped through two 30" pipelines to the Ormen Lange plant on the remote Nyhamna Island. On the island, the gas is processed, compressed and then piped 750 miles across the North Sea to the UK. Approximately mid way to the UK the pipeline crosses the Sleipner platform. Shell took over operation of the plant on December 1, 2007.

One over-riding strategy that helped guide the design and planning process was the need to minimize the number of people required at the plant for maintenance and testing activities. As a result, heavy use of condition monitoring systems for as many components and process systems as possible would be employed. The strategy was clear and detailed specifications were developed for the valve condition monitoring system and multiple suppliers competed in the bidding process.

The V-MAP on line valve monitoring system was one of the systems selected to meet the condition monitoring goals of the Project.

One required feature of instrumentation used in the hazardous oil and gas environment involves assurances that electrical faults or instrument failures will not create enough energy to ignite a potentially explosive atmosphere in the immediate environment. Various strategies are used around the world to protect against potential ignition but the breakthrough for condition monitoring was the development, certification and use of intrinsically safe circuits and devices. Intrinsically safe electrical circuits require very little power to operate and are designed such that normal operation, faults and shorts cannot release enough energy or heat to ignite an explosive atmosphere.

A critical requirement of the Ormen Lange valve monitoring system was the ability to detect through-valve leakage after the valve closes. Through-valve leakage is one of the most important test parameters for the oil and gas industry and certain valves must be tested periodically to verify they will not leak when needed in an emergency. Broadband acoustic emission sensors are employed by V-MAP to detect the high frequency noise caused by very small leaks at high pressure. The leakage noise elevates the broad band emission output of the sensor and also creates an initial peak above 100 KHz that spreads in both directions from the peak when the amplitude increases as a result of increasing leak size.

The sensors and amplifiers used in the field provide the conditioned data in a format needed for automated recording in a safe area away from the valves. Much like the portable systems routinely used for periodic MOV and AOV testing in nuclear plants, the data acquisition units (DAUs) capture multiple channels of sensor data streaming from the acoustic emission sensors, the strain gages and pressure transducers in the field. The DAUs stream the captured data in digital format from the sensors to a server in a remote location. Data from the plant control system is linked to the field data in the server via an OPC link. The plant data includes time stamps for initiation of the valve cycle, limit switch actuations, system pressure at the valve and differential pressure across the valve when the valve is closed.

The V-MAP application running on the server provides automated analysis of the incoming data based on user defined limits in the software. When acceptance criteria are not met the V-MAP user is alerted at his workstation when viewing the main V-MAP dashboard. The visual icons representing each valve change from green to red or yellow based on automated analysis of the data. During the early phases of operation the alarms were allowed to trigger with every cycle such that baseline performance could be established over a range of operating conditions. After 3 years of monitoring, the acceptance criteria for force or torque, cycle time, response time and leakage have been adjusted to reflect the baseline performance at various operating conditions and to help evaluate changes over time.

Condition Monitoring Approach

As discussed above, the critical isolation valves at Ormen Lange include a mix of single and double acting pneumatic and hydraulic gate, ball and flow control valves similar to globe valves.

Strain gages are attached to the valves to detect changes in actuator output or loads in the valve that may affect performance. The precise location of each gage was determined by finite element analysis (FEA). The FEA identified the best location for the gage and the appropriate conversion factors for converting strain to torque or thrust.

Since the actuators are hydraulic or pneumatic, pressure transducers are installed in the supply lines between the hydraulic control solenoids and the actuator cylinder. It is important to point out that the actuators and valves used at Ormen Lange are much larger than the typical nuclear plant valve. The isolation valves at the landfall accommodate the 30” pipeline from the subsea wells. The critical shutdown valves on the export side of the plant are 42” in diameter with a maximum gas pressure at the valve of 3,600 PSI. The hydraulic actuators for these large gate valves can easily apply greater than 250,000 pounds of force to the valve at the maximum hydraulic system pressure of 4,700 PSI.

The leakage criteria for each valve vary by valve and application but the typical acceptance criterion is .02 Kg/sec and .05 Kg/sec. The leakage criteria seem tight but when converted to flow it would be over 100 liters per minute depending on the gas density. The acoustic sensors and signal processing used will detect a leak as low as .1 liters per minute.

The Ormen Lange plant was designed and built to the highest safety standards consistent with IEC 61508 and 61511. IEC 61508 is applied during the design of safety critical systems to ensure that electrical, electronic and programmable equipment are analyzed such that the risks caused by failure of systems or components to perform intended safety functions are minimized. IEC 61511 establishes requirements for the specification, design, installation, operation and maintenance of a safety instrumented system, so that it can be confidently entrusted to place and/or maintain the process in a safe state.

To reach the desired level of safety at Ormen Lange, features such as partial stroke controllers for valves were installed in addition to the condition monitoring system. Partial stroke systems facilitate periodic exercising of valves that cannot be closed during operations. As a result, valves that must remain open for extended periods of time such as those at Ormen Lange can be partially cycled and monitored at some frequency. Both valve and actuator condition are monitored and evaluated after every full cycle and valves that remain open for production reasons can be partially closed in order to evaluate potential changes in performance. Since these valves may be cycled at any moment and multiple valves close at the same instant during shutdowns, it is not practical to capture the periodic test data with portable systems. Automated on line data acquisition takes the human element completely out of the testing process and cycles/test opportunities cannot escape the continuous monitoring process. Even after the valve reaches the closed position, the acoustic sensors continue to stream data to the server where it is combined with system pressure information to assess the potential of a developing leak.

Strain gage devices and hydraulic transducers wait for the next cycle and the command signals from the control room trigger the software to look for activity at the valve. The automated analysis system looks at each parameter and decides when to alert the user.

Data Analysis and Results

The typical valve actuator at Ormen Lange is spring to close single acting hydraulic. However, there are also several double acting hydraulic and some pneumatic actuators. The hydraulic system operates at 4,700 PSI and solenoid valves route hydraulic pressure to the actuator to open the valve and they also release the pressure to allow spring closure.

The gate valves and actuators are both reverse acting which means the valve stem is pulled upward or out to close the valve. When the stem is pulled upward or out of the valve it lifts the gate (obtuator) to cover the orifice and shut off flow. The gate is pushed down by the actuator to open. This creates a temporary orientation issue for an analyst familiar with the operation and signature characteristics of a typical gate valve used in a nuclear plant environment.

The backward looking signatures are easier to keep straight for a single acting spring close actuator because hydraulic pressure opens the valve and the release of hydraulic pressure allows it to close as the spring extends. One of the early analysis issues uncovered by the monitoring and signature analysis process was related to how fast a valve can close as it exhausts hydraulic pressure. The signature data revealed that for the typical actuator the hydraulic pressure required to start spring compression, which also starts moving the valve in the open direction, is 1,200 PSI. The springs reach full compression, which puts the valve in the full open position at approximately 1,750 PSI. However the hydraulic system pressure continues to increase to 4,700 PSI after the valve reaches the full open position. In order for the valve to close, the hydraulic cylinder must release sufficient volume to reduce the pressure from 4,700 PSI to 1,750 PSI before the spring can overcome the pressure force and start to extend which closes the valve. Flow restrictions were found which delayed the start of the closure process and extended the closure time for valves required to stroke within certain limits required by the safety analysis.

There were several different issues that caused the response time problem. In some valves, the size of the exhaust side tubing was increased so the volume could escape the actuator cylinder faster. In other cases, the hydraulic control blocks that contain the solenoid valves were replaced.

The strain sensor data is used to evaluate changes in running force on gate valves or torque on quarter-turn valves that would affect the available margin to operate the valve. Some minor changes in torque have been observed over the first 3 years but not to a level that would challenge the ability of these robust actuators. By evaluating the relationship between hydraulic pressure and force/torque from the strain gage, the analyst can assess changes in the valve and actuator and determine the location of the observed degradation.

The acoustic emission sensors used to monitor the valve for leakage after it closes are sensitive to very low level leakage down to .1 liter per minute. Because of the designs used it is very rare that one of these valves will develop a significant leak and to date there have not been leaks that would challenge the acceptance limits discussed above. However, it is clear that some of these valves do develop very low level leaks from time-to-time that are self correcting. These leaks which are detected by the system are typically a few liters per minute and can be corrected by simply cycling the valve. Debris might normally be expected but the gas is very clean by the time it reaches these particular valves. At this point they are simply monitored because when the valves close the plant or system will typically be headed toward shutdown and lower differential pressure across the valve. The cause of these low level intermittent leaks is not known but suspected to be related to how well the seats mate during closure under different operating conditions.

The valves with partial stroke control systems are exercised regularly and the data is automatically captured and evaluated by the system. Since the valves do not fully close there is little diagnostic information about the condition of the valve gained from a partial stroke test. However, the partial stroke limit switches play an important role relative to stroke time. The amount of time required between the close command, the release of the solenoid, the valve starting to move and then reaching the partial close limit is recorded and trended. Changes in these times could be indicative of changes in the hydraulic system, changes within the actuator or changes within the valve. The simultaneous recording of the strain and hydraulic pressure sensor data helps to isolate whether the change was due to changes within the valve or actuator.

All of the data is captured automatically without user intervention. The data is processed and analyzed and the results made available through the site network, the wider Shell network and outside of the Shell network through the internet. The end result is continuous real time confidence in the condition of critical valves versus the unknown and often changing condition not detectable by periodic testing programs.

Growing Adoption in Oil & Gas

The growing adoption of on line valve condition monitoring in oil and gas closely mirrors what occurred in the nuclear power industry when portable valve diagnostic systems were first introduced. In the early days of adoption by nuclear plants the targets were problem valves known to directly affect safety or plant operations. In the Ormen Lange case it is about getting the most out of the plant at the highest level of safety. This strategy has spread throughout the Norwegian oil and gas community and into other parts of the world as well.

V-MAP valve monitoring systems have been installed on offshore platforms in the North Sea and in the US Gulf of Mexico to monitor critical valves and known problem valves. Similar systems have also been installed on offshore platforms in the Malaysian waters of the South China Sea and most recently in the Tar Sands of Northern Alberta.

In the Tar Sands case, the initial targets are the 3 position coke shuttle valves operated by Rotork motor operators. These large ball valves create multiple flow paths which allow bitumen to flow into the coking tower from one pipe and out of the coking tower through another pipe. These valves are notorious problems that eventually lead to extended maintenance outages when they seize due to excessive build up of hydrocarbon products within the valve. The monitoring approach is to trend increases in the torque required to operate the valve over time and schedule maintenance before the actuator can no longer change the position of the valve. If the valve seizes with the tower full of bitumen it will harden and require extensive manual effort to remove so payback is achieved by avoiding the high cost of losing a coking tower in this fashion.

Considerations for Nuclear Plant Valve Testing

On line valve monitoring is not completely foreign to nuclear power plants in the United States. On line data acquisition was implemented for a small population of MOVs at the Pilgrim Nuclear Plant in the mid-90s as part of the GL 96-05 program. The data acquisition units are not linked to the outside world through the plant IT network as in the Ormen Lange example but they contain sufficient memory to record the required data which is accessed locally by plant personnel. The data acquisition units are connected to strain sensors on the valve stem and current probes necessary to detect switch actuations are installed in the actuator switch compartment.

Unfortunately, on line valve condition monitoring did not gain traction as nuclear plants developed and implemented Generic Letter 89-10 or 96-05 MOV programs or the AOV programs that followed. As a consequence plants have revisited valves at regular intervals to perform the periodic testing required by the MOV and AOV programs. The continual at-the-valve testing requires consideration in the outage planning process and additional testing resources are often required to install equipment and sensors on the valve in order to obtain the required data during the outage.

The many simultaneous outages across the nuclear industry during spring and fall refueling seasons continues to tax the various suppliers and demand for qualified testing resources often exceeds supply. From time-to-time valves fail the test acceptance criteria and an unplanned corrective action is added to the outage workload which may also demand additional resources. The process of finding the appropriate qualified resources to perform the testing, performing the tests during the outage, adjusting the outage workload to accommodate emerging corrective actions and risking extending the outage schedule due to availability of parts may not always represent the most efficient approach. These are the very issues that Shell wanted to avoid at Ormen Lange.

In the Ormen Lange case, the valves test themselves during each operation and the Shell engineer responsible for valve condition monitoring is not even located at the site. Valve testing is not a part of the outage and personnel qualified to perform valve testing are not required. Maintenance is instead a precise orchestra based on the data observed during operation.

Because of Generic Letters 89-10 and 96-05, strain gage sensors of some type are already installed on many nuclear plant MOVs and some AOVs. The addition of data acquisition devices that can connect field sensors to the plant network and to the outside world can be easily adopted at a lower cost than once expected. At-the-valve data acquisition units can communicate data using a dedicated valve condition monitoring network or the existing plant network directly to the valve program engineer's desk near real time. As a consequence, valves test themselves and all program testing requirements are completed as the valves cycle during normal operation or during the shutdown process. Like Ormen Lange, this online approach makes outages without at-the-valve MOV or AOV testing a reality.

One hurdle to nuclear plant adoption may be how to overcome the real-time stream of accurate information on valve condition while the plant is operating. In keeping with the highest standards of safety this is desirable. However, it can also give operators too much information and lead to unnecessary actions. This issue is also a concern in the oil and gas facilities where on line systems are currently used. Operations and maintenance personnel must be conscious of not blurring the line between the systems required to operate the plant and the condition monitoring systems required to maintain components such as valves. It must remain clear that an alarm in the condition monitoring system does not necessarily mean the component is not operable and this type of alarm should remain invisible to operators. However, an alarm in the condition monitoring system does alert maintenance and engineering that something is changing and it should be evaluated. From time-to-time there may be alarms in the system that after complete evaluation require immediate action.

Use of on line approaches with ASME Appendix 3 (OMN-1)

The ASME working group responsible for the OM codes related to the operation and maintenance of nuclear power plants and specifically the MOV working group continue to process inquiries related to implementation of Mandatory Appendix III of ASME OM-2009 (also known as OMN-1). Several formal and informal inquiries related to Appendix III relate to test frequency and grace for missed periodic tests.

Appendix III represents a change from the prescribed test intervals of Generic Letter 89-10 toward empirically derived frequencies based on test data from each valve or from groups of similar valves. The "every 2 years" of NRC Generic Letter 89-10 and the variable intervals of Generic Letter 96-05 and the Joint Owners Group Program are relics of the past under Appendix III rules. The new approach of Appendix III requires nuclear plant licensees to consider margin, risk significance, performance trends, preventative maintenance schedules and other factors that could affect performance when setting test frequencies for program valves. It is a highly data dependent and analytical process not too dissimilar from the IEC EN 61508 processes used to establish failure rates and diagnostic coverage of components that effect safety in oil and gas installations.

As plants adopt Appendix III they will analyze existing data and set test frequencies based on the above discussion and factor those tests into future outage schedules. Since the average number of MOVs affected by Appendix III and Generic Letter 89-10 is approximately 100 per nuclear reactor and each MOV on potentially different schedules for testing or other program activities, the chances that one or more may be overlooked or a scheduled test requirement missed is a real concern which has already occurred for at least one plant.

Both of these issues and others are resolved by continuous monitoring of program valves and automated data analysis. However, since the software driven analysis can only be used to assess certain hard coded criteria such as running loads, available thrust or torque, total thrust or torque and other key events, manual analysis by a skilled person or program engineer is still required at some frequency. As suggested by the overriding theme of Appendix III the manual, visual review of data would be based on the abundance of data generated by each operation over the life of the valve.

Disclaimer

The views discussed in this paper are those of the author and do not necessarily reflect those of any of the organizations discussed herein. The conclusions, interpretations, recommendations, or any opinion expressed above may or may not be completely the same as those of Score Group, Shell, the ASME MOV working group or any other organization referenced in this paper but are based solely on the experience of the author relative to valve condition monitoring over the past 25 years in a range of industries.

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FIGURE 1
Ormen Lange Location

FIGURE 2
The Ormen Lange Plant on Nyhamna Island, Norway

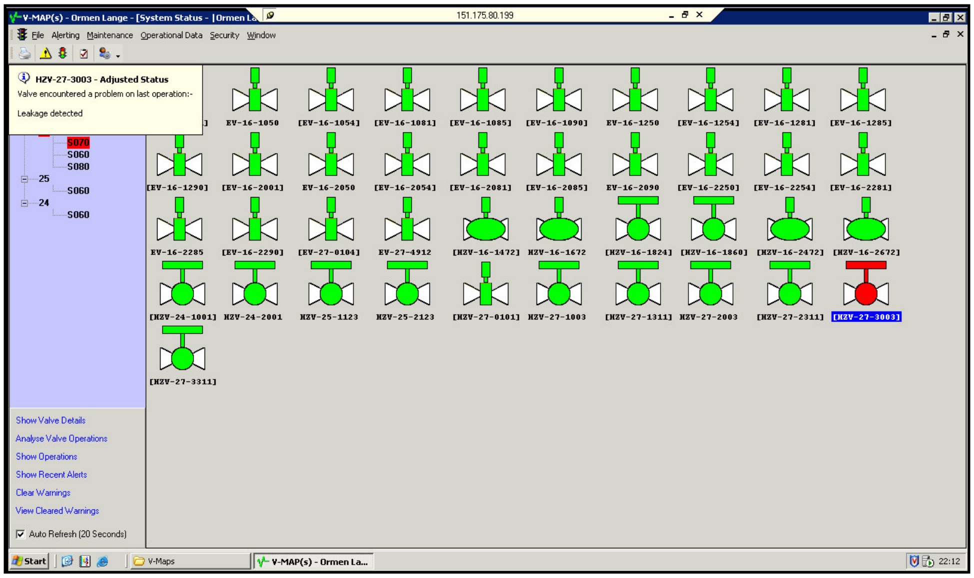

FIGURE 3
V-MAP Dashboard

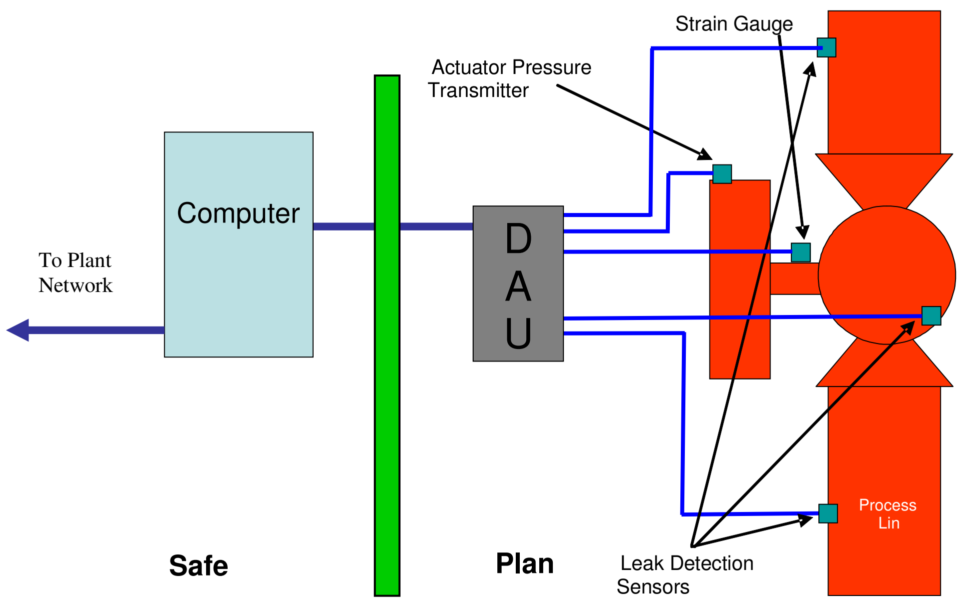

FIGURE 4
V-MAP Functional Diagram

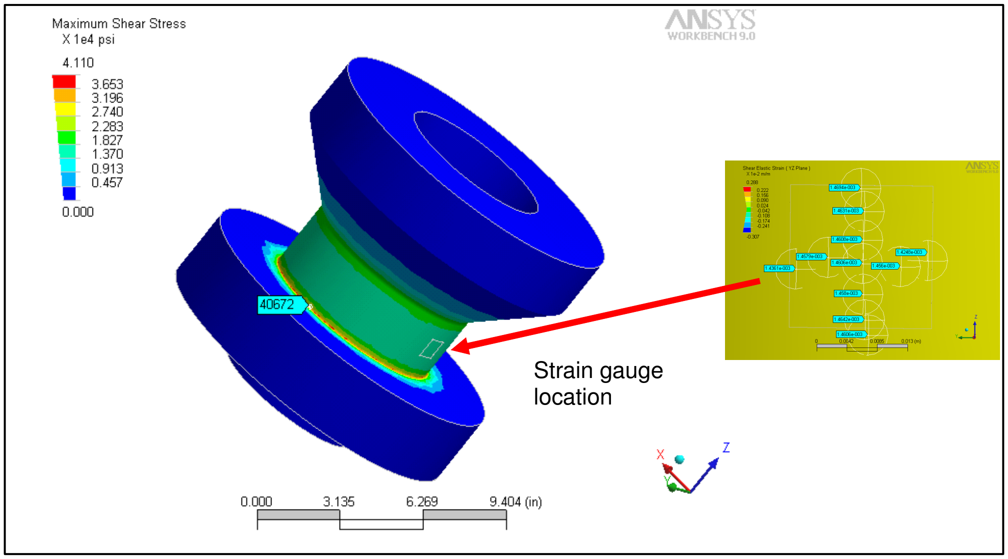

FIGURE 5
FEA of Ball Valve Mounting Stool

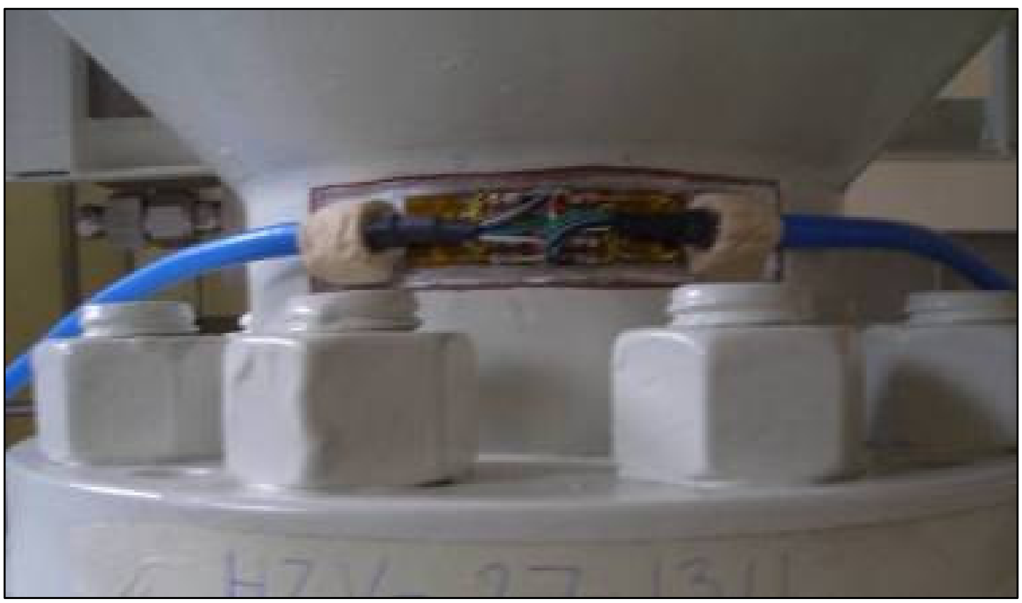

FIGURE 6
Installed Strain Gages

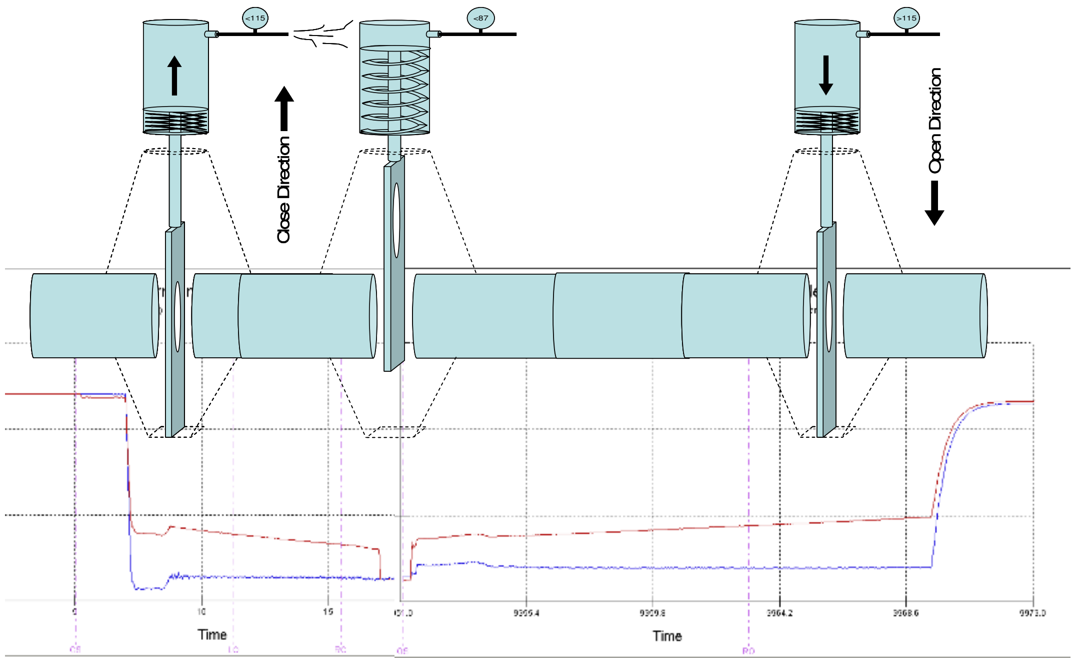

FIGURE 7
Single Acting Gate Valve Model and Example Signatures