STRESS talk 2011

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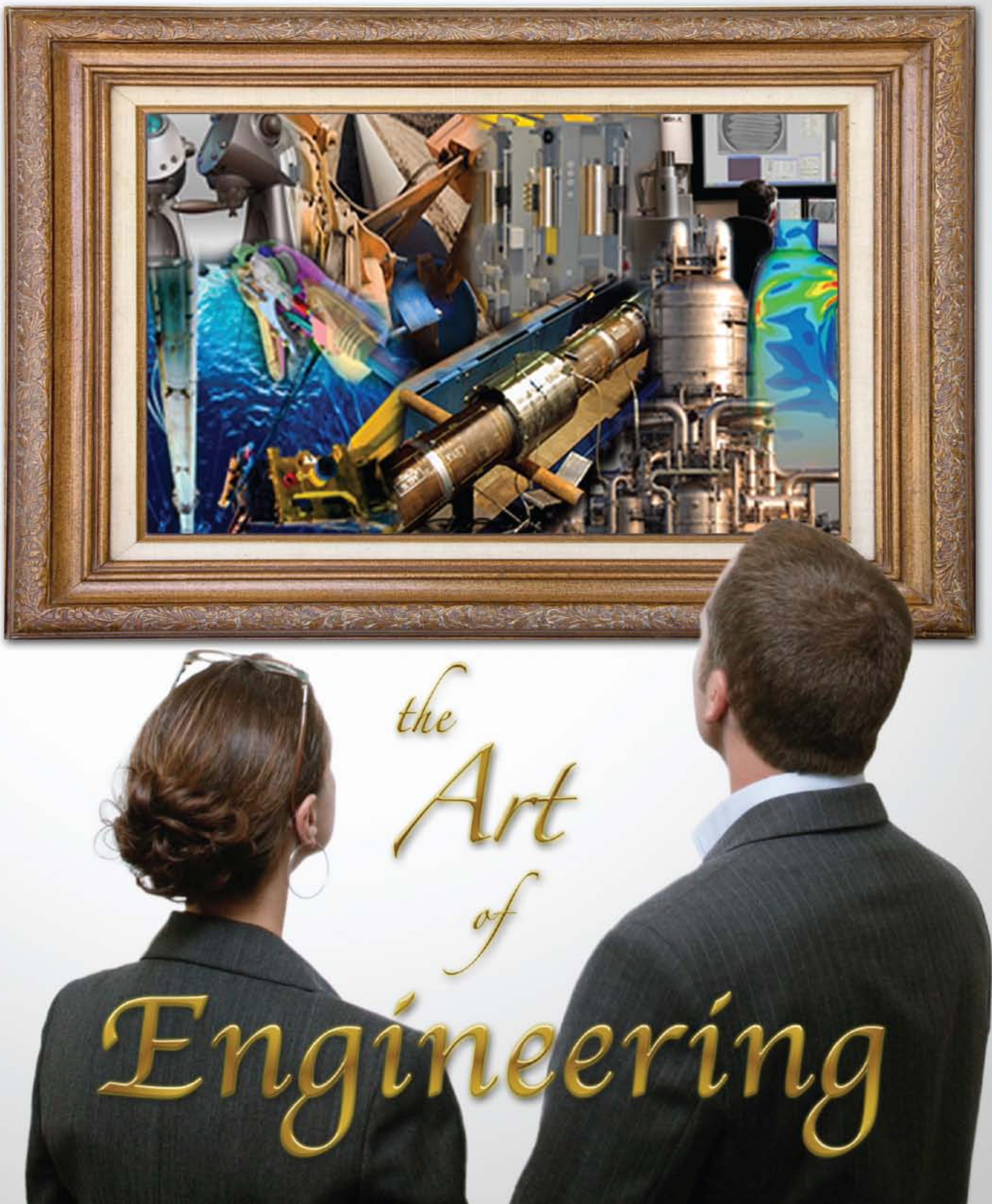


the Art of Engineering

contents

2011 Technical Training and Seminars

Stress Engineering Services is offering training courses and seminars in four key practice areas: Downstream Chemical & Refinery, Pipelines, Upstream Oil & Gas, and Subsea Engineering. For more information regarding our technical training courses and seminars, contact Brittany Graybill, Training Coordinator, at (281) 671-2551 or email: brittany.graybill@stress.com.

Downstream Chemical & Refinery

- API 579
- API RP 571
- ASME Boiler and Pressure Vessel Codes
- Coke Drum Reliability
- Covered Piping System Programs (CPS)
- Fixed Equipment Repair and Failure Analysis
- High Temperature Fitness-for-Service
- Initial Phases of Failure Analysis & Investigation
- Vibration Analysis for Fixed Equipment

Subsea Engineering

- Evolution of Subsea Deepwater Engineering and Current Day Applications
- Fundamentals of Flowline and Pipeline Design
- Subsea Corrosion Management
- Subsea Field Development
- Subsea Systems Engineering

Upstream: Oil & Gas

- API RP 75 and New Requirements for U.S. Outer Continental Shelf Facilities
- Drilling Riser School: Understanding the Design and Analysis of Deepwater Drilling Risers
- Evaluation of Vibration and Fatigue of Offshore and Subsea Equipment
- Fitness-for-Service Assessment of Deepwater Flowlines and Risers
- Fundamentals of Design for Floating Production Vessels
- High Pressure/High Temperature Fitness-for-Service
- Integrity Management for Offshore Floating Production Systems
- Oilfield Metallurgy and Corrosion
- Riser Design for Floating Production Systems

Pipelines

- Composite Repair Workshop for Plants
- Pipeline Composite Repair Workshop
- Pipeline Engineering Based Integrity Management Workshop

STRESS ENGINEERING SERVICES INC.
13800 Westfair East Drive
Houston, Texas 77041-1205

Success Through Good Service, Positive Culture, and Leadership

by: Joe R. Fowler, Ph.D., P.E., President

The year 2010 was a very good year for Stress Engineering Services with service to 798 clients and record sales. During the year we also completed several new important capabilities:

- Expansion of our Houston metallurgical laboratory to meet the needs of our twenty metallurgists
- Completion of our sour gas testing laboratory at our Waller, Texas facility
- Completion of our creep and elevated temperature testing facility at our lab in Cincinnati, Ohio

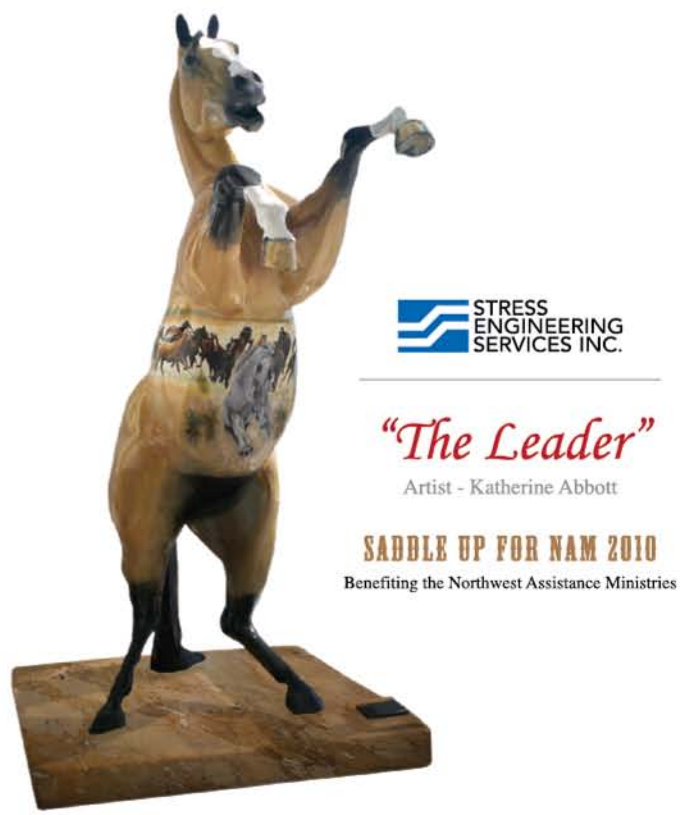
Each of these represents an important advancement in our ability to solve clients' difficult technical problems.

We have recently finalized the acquisition of Calgary Alberta based Zeus Engineering. The acquisition will enable us to use our overall skills to better serve Canadian clients with our renowned design, analysis, testing, and metallurgical services. This new office will be called *Stress Engineering Services Canada*.

The April 2010 incident that occurred in the Gulf of Mexico has been a challenge for many of our clients and us as well. We have been asked to assist many clients with safety related projects, and a number of clients have experienced a slowdown in their Gulf of Mexico work from the lack of drilling permits. We believe our independent, third party testing and analytical skills will become even more important as operators and contractors are asked to demonstrate the safety of their equipment, designs, and processes.

We are blessed with an extremely good culture at Stress Engineering Services and I am personally pleased that our employee owners continue to participate in various charitable works. Some of last year's projects included a very successful United Way campaign with over $73,800 raised, support for Northwest Assistance Ministries programs, and our strong Susan B. Komen and BP MS 150 fund-raising teams.

Thanks again to you, our clients and supporters, for allowing us to help you suceed!



Coupled Aero-Servo-Hydro-Elastic Analysis of Onshore and Offshore Wind Turbines

by: Puneet Agarwal, Ph.D.

Over the past decade, wind energy has grown tremendously worldwide. In the US alone, wind energy installations grew from less than 2 GW (Giga Watts) in 2000 to about 35 GW in 2009. While all of these were land-based developments, offshore wind energy is lately gaining momentum as well. Several offshore wind farms are now in advanced stages of planning in the US. With such growth, adequate tools and expertise for analysis and design of wind turbines are also needed.

A wind turbine is a complex engineering system, whose analysis requires proper coupling of various parts of its physics namely aeroelasticity, dynamics, control systems, hydrodynamics, etc.

It is important to understand such coupled analysis as it is required for design of wind turbines. Design standards for wind turbines, such as those from the International Electrotechnical Commission (IEC), also require such coupled analysis.

COUPLED SIMULATION

One widely used tools for the coupled aero-servo-hydro-elastic simulation of wind turbines is FAST (Fatigue, Aerodynamics, Structures and Turbulence) developed at the National Renewable Energy Laboratory (NREL). Other simulation codes are available as well; they all follow somewhat similar models.

Inflow Wind

The three orthogonal components of wind velocity are simulated on a grid of points on the rotor plane. Such a wind field is a multivariate spatio-temporal stochastic process, which is simulated using the power spectrum and a coherence spectrum that describes the spatial-correlation structure of wind. A wind shear law is also specified. A turbulence model describing variation of turbulence intensity is also needed. It is important to note that not only do the parameters of the selected models vary between sites, but the models themselves can also be different at different sites.

Aerodynamics

Aerodynamic forces on the rotating blades of a horizontal-axis wind turbine are commonly computed using the blade element momentum theory. In this theory, forces and moments applied on the rotor blades are obtained by equating those from blade element theory (where each blade section is assumed to act as a two-dimensional airfoil that produces aerodynamic forces) and momentum theory (where thrust and torque forces exerted on a rotor by the flow stream are found using mass and momentum conservation on an annular control volume surrounding the flow). Inputs needed in simulation are the airfoil geometries and aerodynamic coefficients. Note that modern wind turbine blades typically have several different airfoil sections along their length.

Controls

An integral part of modern wind turbines are control systems. In the blade pitch control system, the pitch angle of a blade is increased in response to an increase in the instantaneous wind speed in order to reduce the rotor speed. Other forms of control strategies include control of generator torque, brake application on the high speed shaft, brake deployment on blade tips, and nacelle yaw. Each wind turbine can have a different control system that should be algorithmically implemented in the simulation software. While controls are designed to optimize power production from the generator over a range of wind speeds, they also significantly impact instantaneous structural loads.

Structural Dynamics

The structural dynamic model for a wind turbine in FAST is based on a combined modal and multibody dynamics formulation, and it consists of several flexible bodies (the tower, three blades, and a drive shaft) and several rigid bodies. In case of offshore wind turbines, motions of the support platform are included. The degrees of freedom (DOFs) of the tower and blades include their first few bending modes in the two orthogonal directions. The yawing motion of the nacelle, the generator azimuth angle, and the drivetrain compliance constitute other DOFs. The user must choose the necessary combination of DOFs to appropriately model a horizontal-axis wind turbine.

Hydrodynamics

FAST uses Morison's equation to compute hydrodynamic loads for the monopile support structures. Wave kinematics is simulated with the irregular linear Airy wave model. Nonlinear wave formulations have been added recently in FAST. Correlation between wind and waves needs to be modeled. Misalignment between wind and wave directions is important as there is significant aerodynamic damping in the direction of wind when turbine is in operation. While FAST is quite mature for onshore and fixed-bottom offshore wind turbines, its hydrodynamic modules are being updated to properly model floating offshore turbines.

Stochastic Simulations

In order to derive long-term nominal loads for design, stochastic time domain simulations of turbine response are performed for various combinations of environmental random variables as per their joint probability distribution functions. Mean wind speed and turbulence intensity are random variables describing wind, and significant wave height and spectral peak period describe waves in case of offshore wind turbines. Several (on the order of 30) simulations for each environmental state must be performed to obtain meaningful short-term statistics of extreme turbine loads. Typical duration of simulations is 10 minutes, as is the standard practice in wind engineering.

SIMULATION EXAMPLE WITH NREL 5 MW BASELINE MODEL

Turbine Model

A 5 MW wind turbine model, which was developed at NREL and closely represents utility-scale offshore wind turbines being manufactured today, is used in the simulation example here. The turbine has a hub height of 90 meters above the ground (for onshore version) or above the mean sea level and a rotor diameter of 126 meters. The turbine is a variable-speed and collective pitch-controlled machine, with a maximum rotor speed of 12.1 rpm. The rated wind speed (wind speed at which blades start to pitch) is 11.5 m/s, while the cut-in and cut-out speeds (wind speeds over which a wind turbine operates) are 3 m/s and 25 m/s, respectively. The offshore version of this turbine is assumed to be sited in 20 meters of water and has a monopile support structure, which is assumed to be rigidly connected at the mudline.

Turbine Response

Figure 1 shows the average, maximum, and minimum statistics of the 10-minute extreme fore-aft tower bending moment (FATBM) for all wind speed bins. Multiple 10-minute simulations are performed for each wind speed, 10-minute extreme (largest) load is computed for each simulation, and then the statistics are estimated over these multiple simulations. It is observed that the mean load increases with wind speed, up to the rated wind speed of 11.5 m/s, and then decreases. Importantly, there is significant scatter in loads above the rated wind speeds. Out-of-plane bending moment (OoPBM) at a blade-root also exhibits similar behavior, which is due to pitch-control actions. These kind of summary plots are useful since these inform which wind speeds would govern loads and, hence, simulation effort should be focused in the most important bins. Variation of the extreme loads with wind speed and wave height can be similarly studied, though waves tend to have significant effect only on tower loads.

Power spectrum of OoPBM, which illustrates dynamic characteristics of a wind turbine, is shown in Figure 2. Important peaks in the power spectrum are seen at 1P (corresponding to the rotor rotation rate which is 0.2 Hz

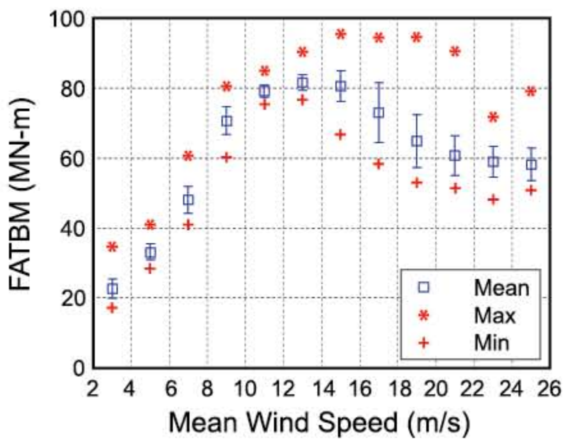


Figure 1: Statistics of short-term (10-minute) load maxima as a function of wind speed for Fore-aft Tower Bending Moment (FATBM) at the base of tower, based on 200 simulations per wind speed bin.

at, and above, the rated wind speed) and multiples, which are the dominant peaks, as well as at resonant frequencies associated with edgewise and flapwise modes. The tower fore-aft bending moment exhibits peaks at 3P and its multiples for a three-bladed wind turbine and, of course, peaks at tower natural frequencies.

Load Extrapolation

IEC 61400-1 and 61400-3 design guidelines recommend the use of statistical extrapolation methods to predict extreme turbine loads for a desired return period. Use of such probabilistic approach is warranted since N-year environment does not typically result in N-year response, because of nonlinearity and high variability in turbine response. Direct integration and the inverse first-order reliability method are two common extrapolation methods. These methods, speaking in a somewhat basic sense, require 'combining' short-term conditional load distributions with the joint probability distributions of environmental random variables. It is critically important that short-term distributions, with stable tails, are adequately estimated. Figure 3 shows the short-term distribution of OoPBM for the governing environmental state. The distribution is stable only after extremes from many (60 here) simulations are used, when the tail fills in. Only such stable distribution can be extrapolated to 20-year level (depicted by p_3 fractile in Fig. 3) with any confidence.

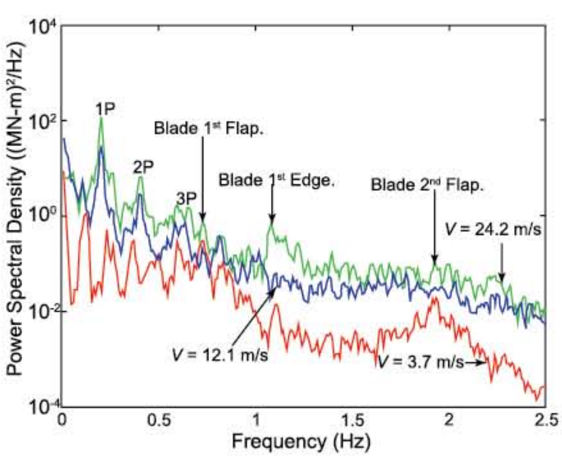


Figure 2: Variation of power spectral density with mean wind speed for out-of-plane blade moment.

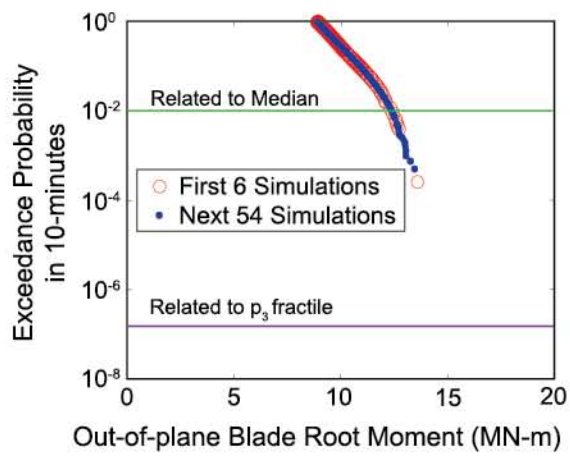


Figure 3: Short-term load distribution of 10-minute load extremes for the environmental state (V = 14 m/s, Hs = 5.5 m) that governs out-of-plane bending moment (OoPBM) at a blade root. The distribution is to be extrapolated to the indicated p_3 fractile that is related to a return period of 20 years.

SUMMARY

Load analysis of wind turbines requires an understanding of contrastingly different physics of parts of a wind turbine in addition to the interfacing between these parts. These parts affect each other to such an extent that a coupled analysis is the only rational approach for analysis. Stress Engineering has expertise in almost every aspect of wind turbine physics, including these coupled analyses. We are suitably poised to meet engineering demands of a growing wind energy industry.

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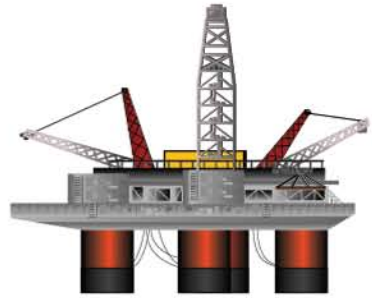
Upstream Practice Update



by: Charles A. Miller, P.E.

2010 was a very good year for Stress Engineering's upstream practice. We continued to grow to over 50 engineers devoted to work in this sector of the Oil and Gas (O&G) industry. As we grew, our focus remained on maintaining a high level of industry experience amongst our upstream personnel, who have an average of 15 years of O&G industry experience.

Floating Production Systems

Our 2010 efforts included design projects for floating production system risers to be deployed in the Gulf of Mexico and off the coasts of Brazil, Southeast Asia, and West Africa. Many of these projects were performed in conjunction with flowline or pipeline design work performed by Stress Engineering's subsea group.

Mobile Offshore Drilling Units (MODUs)

We also participated in over 150 projects related to the design and operation of mobile offshore drilling unit (MODU) riser systems, in support of operating companies, drilling contractors and equipment manufacturers, and drilling programs around the world. These projects included design and analysis for both ultra-deepwater drilling riser systems, for water depths up to 12,000 feet, and surface blow-out preventer (BOP) drilling riser systems. Stress Engineering continues to be the experts in riser recoil analyses for emergency disconnect operations as well as weak point analyses. The events of 2010 have helped demonstrate the importance of weak point analyses when designing deepwater wells.

Integrity Management

Our integrity management (IM) work continued to thrive as we collaborated with operating companies to maintain, repair, and enhance their operations and facilities. This work included helping to maintain the marine and structural (both hull and topside) integrity of floating production systems as operators attempted to bring new production onto their existing facilities and as they faced new regulations and environmental conditions that were beyond the facilities' original design conditions.

Deepwater Applications

Many of our engineers continued to help equipment manufacturers design and develop components and product lines that address the new challenges facing the deepwater O&G industry. These engineers also helped operators evaluate both new and old equipment designs to determine fitness for the harsh environments that new deepwater wells and facilities will encounter.

Equipment Monitoring and Data Analysis

As our upstream practice continued to expand, we also continued to offer new services. Stress Engineering developed new instrumentation for evaluating the dynamic response of subsea equipment (see page 17) in order to compliment our existing and extensive data analysis capabilities. For operators, this translated to a better understanding of potential fatigue and maintenance issues that can be addressed before major problems develop.

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High Temperature Life Assessment

by: Greg Garic, P.E.

Predicting the remaining life of components operating in the creep regime is one of the trickiest problems encountered in the fitness-for-service world. Heater tubes, steam methane reformer tubes, and FCCUs are a few of the components that experience a combination of high temperature, stress, and long exposure that results in the insidious degradation of the material via the process referred to as "creep."

Creep behavior is easy to describe...

Creep is the time dependent deformation of a material under load.

At lower temperatures, deformation is normally dependent on load, but not time. For example, a simple cantilever beam (Figure 1) at atmospheric temperature will deflect a certain distance under load, but the deflection won't increase over time. If it deflects ½" after the load is applied, come back in 20 years and the deflection will still be ½". Not so in the creep regime! A cantilever beam may initially deflect the same ½" upon initial application of the load, but as time passes, the deflection will continuously increase and, in fact, accelerate with the passage of time.

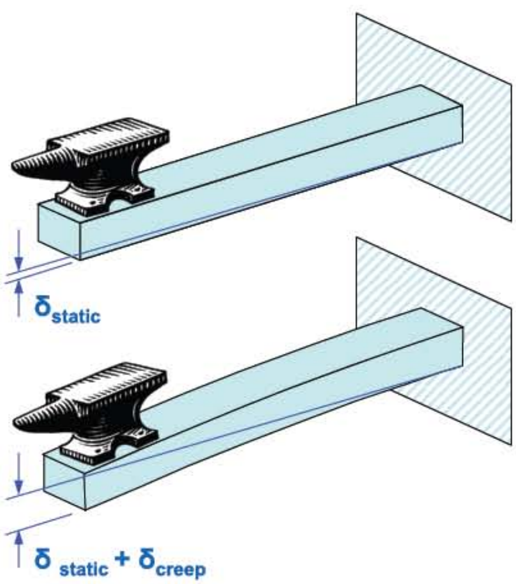


Figure 1: Cantilever Beam

DIFFICULTIES IN EVALUATION OF CREEP DAMAGE

Several aspects of creep damage make it one of the most difficult mechanisms to evaluate.

Microscopic examination of creep-damaged materials yields unreliable indications of damage. In very advanced cases of creep, micro-cracks are sometimes visible at the junction of grain boundaries (so called "triple point" cracking, see Figure 2). But in many cases, these cracks are not visible, even in a failed component. Thus, the presence of cracking presents a one-sided indicator: if it's present, very advanced creep damage is confirmed; if it's not present, no conclusion can be drawn.

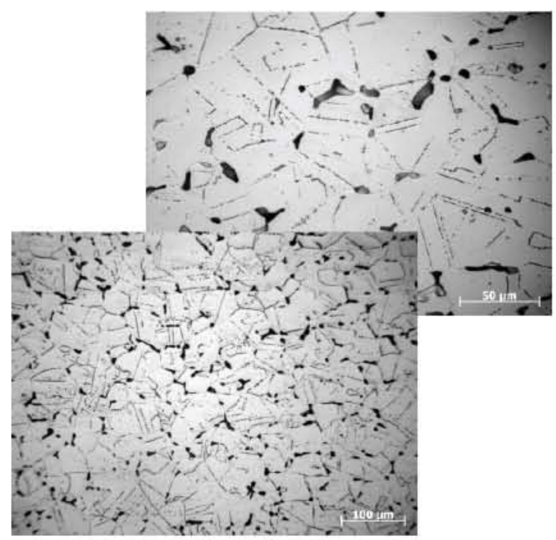


Figure 2: Classic Creep Voids

Inherent variability of a material's creep performance is another source of difficulty. Creep tests conducted on random heats of material conforming to the same specification can show variations in creep life of up to an order of magnitude. Even materials from the same heat can show variations of 2 to 5 times. Thus, the use of generic data (e.g., API 530) requires significant conservatism.

AN APPROACH TO CREEP LIFE MANAGEMENT

High-temperature damage can be caused by numerous factors, including:

- Flame Impingement
- Coking
- Aggressive Operation (i.e., normal operation at high temperatures)
- Long-Term Operation

The effects of high temperature exposure can include:

- Creep
- Microstructural Degradation
- Carburization
- Metal Dusting
- Fireside Oxidation

At Stress Engineering, we advocate an inception-to-completion approach to life management of components in the creep environment. Creep life management requires a combination of all methods: creep life calculations, inspection, microscopic examination, measurement, predictive modeling (CFD), and testing.

In an operating process plant environment, we typically view creep life assessment activities as three phases related to the turn-around (TAR) cycle: Pre-TAR, TAR, and Post-TAR.

Pre-TAR

During the pre-TAR phase, operating temperature and pressure data can be collected and creep calculations can be performed based on average or lower bound creep properties taken from, for example, either API 530 or API 579. The goal of the pre-TAR phase is to identify components that will require more detailed follow-up during the TAR.

Data Review – The pre-TAR data review must rely on numerous data sources such as DCS pressure and temperature data, old handwritten data logs, IR scans (Figure 3), process temperature records, and frequently on anecdotal information and memories of long-time plant personnel. Typically, DCS data are available (and easily accessible) going back for several years. Prior to that, records are often spotty.

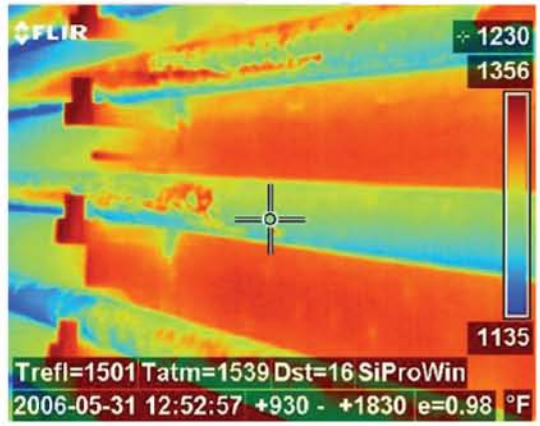


Figure 3: Creep Life Assessment

Calculations - Calculations are usually performed in two phases: screening calculations and detail calculations. Screening calculations are based on worst-case pressure and temperature assumptions. If a component is predicted to have adequate remaining life under these conditions, no further work is necessary on that component. Components that can't pass under the worst-case conditions must undergo more detailed assessment with more realistic temperature and pressure profiles.

TAR

The TAR is an opportunity for careful inspection of components. For high-temperature components operating in the creep range, this would always include a close visual inspection for oxidation or deformation. Additional techniques such as field metallurgical replication (FMR), hardness, thickness measurements, and deformation measurement (e.g., tube diametrical expansion, tube sagging, or bulge size or growth) are all used to develop a composite picture of the component condition.

Figure 4: Local Overheating of 9Cr Tubes

Figure 5: Tube Sag

Occasionally, inspection reveals obvious problems such as bulged or sagged heater tubes (Figure 4 & 5). More often, results indicate no obvious problem. Thermal degradation (e.g., spheroidization or graphitization) is to be expected (see Figure 6), and in itself, usually does not indicate end of life.

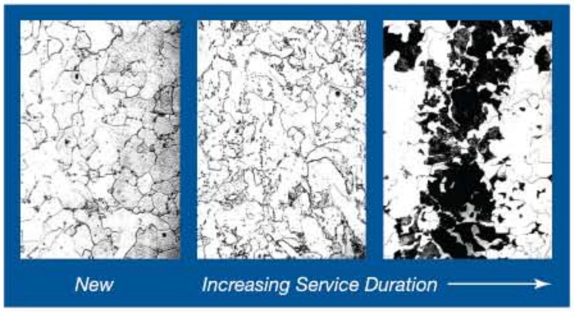


Figure 6: Micro-structural Thermal Degradation

Material Removal – If calculations indicate that more than 50% of life is expended, or visual inspection suggests advanced tube damage, it is usually wise to collect material for subsequent (post-TAR) creep testing. This usually involves removal of several "representative" samples of the component material. The sample should be representative of the worst material that will remain in service. That is, material that is being replaced because of severe overexposure would not be appropriate for testing.

Post-TAR

Post-TAR activities are typically of three types:

- **Creep testing** - to establish actual material conditions
- **Monitoring** – continued or improved monitoring of temperature and load
- **Follow-up calculations** – to quantify the effect of changes in temperature and pressure on component life

If operating history data are sparse, creep testing is the only definitive way to evaluate remaining tube life. In essence, this consists of a constant-load tensile test performed at elevated temperature. To allow the testing to be conducted in a reasonable amount of time, the testing is conducted at temperatures and stresses higher than the operating conditions.

Typically, several test samples are collected from an area of suspected creep damage with as many as five individual test specimens cut from the sample. An individual creep test (of one specimen) usually runs for several weeks, and a test program on several test samples typically requires 4 to 6 months.

Special Cases

In a typical refinery, two high-temperature components—heater tubes and steam methane reformer tubes—constitute such a large percentage of the equipment at risk for creep damage that some discussion of their unique issues is warranted.

Heater Tubes – present some special issues for creep, but also opportunities for savings. Because there are so many heaters in refineries, site-wide heater screening assessments are a cost-effective way to identify the potentially troublesome heaters and minimize the cost of investigating low-damage heaters.

A typical site-wide heater assessment begins with identifying the highest pressure and temperature experienced by each heater. Worst-case screening calculations are then performed on each heater. Our long-term experience at many refineries has shown that, typically, 80% to 90% of the heaters will show significant remaining life and can continue operation without concern. The operator's energy (and money!) can then be focused on the 10% to 20% of the heaters that are potential troublemakers.

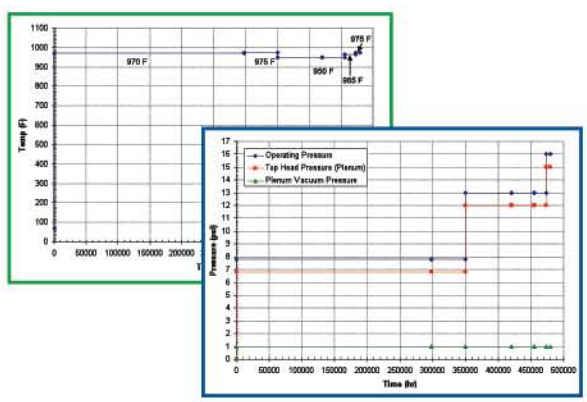


Figure 7: Detailed Assessment

For the heaters that are at risk for creep damage, detailed calculations are performed to predict remaining creep life. Detailed calculations require more file research and DCS history. Pressure and temperature histories, such as those shown in Figure 7, are constructed for each heater. More complicated factors are often included, such as:

- Pressure drop along the length of a tube
- Regular pressure and temperature changes related to coking
- Tube temperature variations in different parts of a heater

All of these factors are used in either Larson-Miller or MPC Omega calculations to establish more accurate tube life estimates.

Steam Methane Reformer (SMR) Catalyst Tubes – SMRs generate some of the hottest routine operating temperatures in a refinery. Similar to heater tubes, they are direct-fired. The operating temperatures can routinely range from 1800°F to 2100°F. These tubes typically are made from cast microalloys that are expensive and can be difficult to obtain on short notice. For these reasons, life prediction and extension are extremely important in SMR service.

Unlike many other high-temperature components, catalyst tubes are regularly inspected for wall thickness and diameter at intervals of 6 months to 2 years. These frequent and close inspections can be used to monitor tube condition and increase the accuracy of life predictions.

Another unique aspect of SMR catalyst tubes is the location of crack initiation. The thermal gradients and their resulting stress distribution, along with the through-wall microstructural variations, yield crack initiation in the inner third of the tube wall. These cracks typically propagate to the inner wall, and eventually begin to progress outward to the outer wall.

Classical creep crack growth models cannot be applied easily in this environment. Special techniques have been developed to address these problems.

Predictive Modeling

Accurate calculation of metal temperatures is vital to high-temperature life assessment. In many cases, such as new design or remediation of chronic operating issues, computer modeling of the flow and temperature properties is the only way to accurately address the thermal behavior of the system.

Stress Engineering performs computational fluid dynamic (CFD) analysis of heaters to address issues such as:

- Heat transfer prediction
- Burner-to-burner interaction evaluation
- Flame impingement evaluation
- Improvements in flame shape and NOx performance

HIGH-TEMPERATURE CREEP TESTING

The foundation of our company was rooted in finite element analysis for the nuclear and oil & gas industries. Finite element analysis was highly specialized when the company was founded in 1972. Early in our development, we realized the need to ground analytical work with a firm experimental footing. Thus, our entry into the strain gage business, and later, the full-scale test labs of our Houston campus, supported the testing of upstream threaded connectors and riser components.

Stress Engineering's state-of-the-art creep lab, located at our Cincinnati Ohio facility, began operations in 2010. The development of the creep lab recognizes the union of advanced engineering analysis and solidly grounded testing.

Stress Engineering Creep Lab

No other company provides both a creep test lab and advanced analytical capability to perform stress analysis and creep testing (to our knowledge). This truly integrated capability involves key engineering personnel in both analysis and testing working side-by-side to design the best tests, perform the most appropriate and accurate analysis, and deliver meaningful, technically advanced, and empirically grounded life predictions.

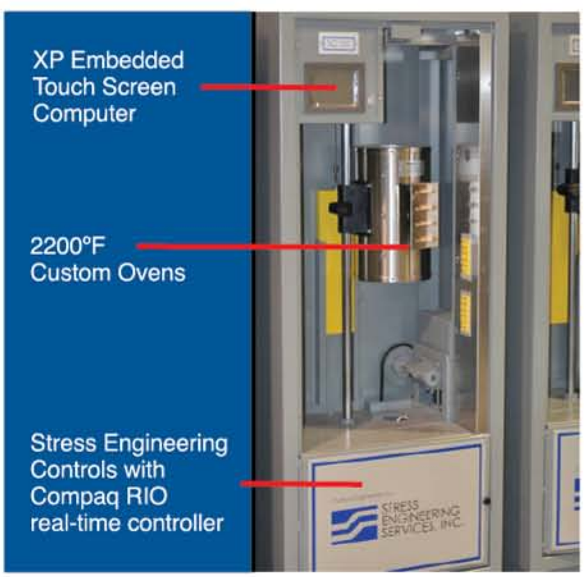
Currently, our Cincinnati lab operates 54 creep machines, including:

- 27 Satec M-3 (6 kip) machines
- 7 Satec JE (20 kip) machines
- 8 Stress/Armco (6 kip)
- 10 Stress (1 kip)
- 2 Amitek (100 kip) machines – These machines allow component-level work that cannot be performed in any other lab in the US.

State-of-the-Art Facility

Our creep lab makes use of many refurbished frames; however, the instrumentation, controls, mounting hardware, and ovens all incorporate the latest available technologies. Our glass scale extensometers provide a resolution of ±0.5 micron. Innovative specimen and extensometer designs provide accurate and reliable measurement. A three-zone heating system provides ±1°F temperature stability (well beyond the ±3°F required by ASTM 139). The custom digital control system records all data at controlled intervals throughout the test (a significant improvement from the once or twice-a-day measurements common at many labs worldwide). More enhancements are coming, for example:

- Strain-increment based data logging logic is currently under design
- Direct posting of strain vs. time data to a web page to allow clients (and Stress project managers) direct, password-protected access to their data in real time.



6 kip Machines

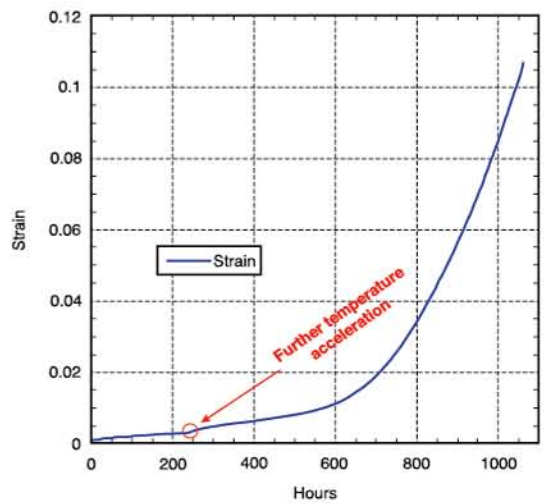


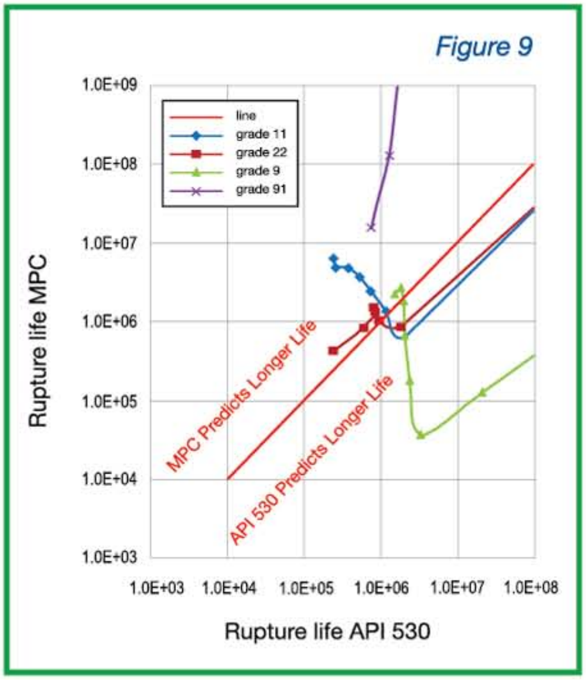
Figure 8: Typical Creep Test

Test data from a typical MPC Omega test is shown in Figure 8. The initial creep rate and Omega phases are clearly visible, as is the point of increased temperature acceleration at the beginning of the Omega phase.

MPC Omega vs. Larson-Miller (API 530) Life Predictions

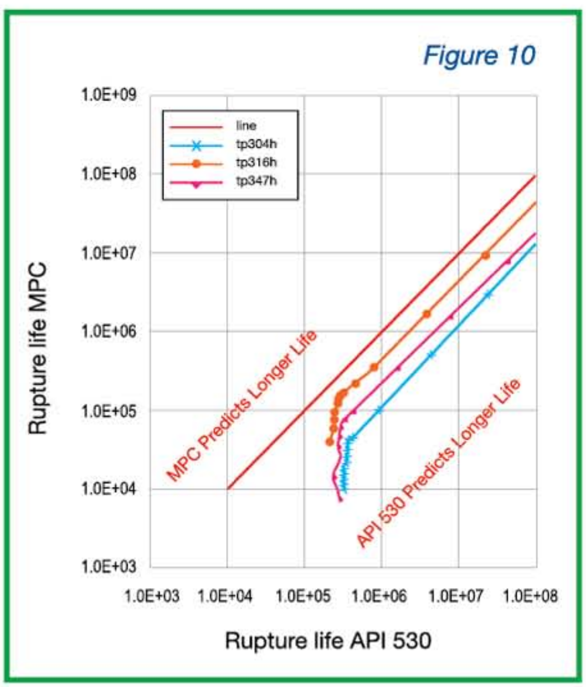
The importance of creep testing is clearly illustrated by comparing the life predictions from the two main methods in use today: the MPC Omega method and the Larson-Miller method used in API 530.

The following charts compare the life predictions by the two methods for a number of materials at different temperatures. Points on the red 45° line would indicate perfect agreement between the two methods. Points



above the red line indicate longer life predictions by the MPC method; points below the red line indicate longer predictions by the MPC Omega method. All results are based on the mean life predictions for both methods. Minimum life predictions are very similar.

For the three stainless steels shown in Figure 9, the API 530 method consistently predicts longer life, with MPC predictions more conservative by a factor of 3 to 10.



For these materials, although a discrepancy exists between the two methods, a consistent pattern is apparent over a range of temperatures.

For the low chrome steels in Figure 10, no consistent pattern is apparent. For most materials, MPC is more conservative at some temperatures, while API 530 is more conservative at other temperatures. For P91, MPC predicts longer life by 2 to 3 orders of magnitude!

Confronted by heater tube or SMR life predictions, the operator has to "pick" which method to use. This decision can be confusing and arbitrary unless supported by sound application of creep testing.

ECONOMIC DECISION-MAKING

Component life is ultimately an economic question. Higher temperatures typically mean higher throughput, but shorter life. Stress Engineering can help operators by providing a clear understanding of life degradation at increasing temperature.

SUMMARY

We are fully committed to high-temperature engineering. We have experts in every phase of analysis for high-temperature problems:

- Predictive CFD modeling – for design and troubleshooting
- Stress analysis – to establish the stress fields that drive high-temperature damage
- Creep damage and life prediction – by MPC, Larson-Miller, Kachanov or any other appropriate damage model
- Metallurgy – for material selection, performance, and failure investigation
- Field inspection and testing – field metallurgical replication (FMR), hardness, strapping, and visual inspection to understand the condition of aging components
- Creep testing – our new state-of-the-art lab provides test data to anchor calculations in the real world

Stress provides an inception-to-completion approach to high-temperature life management.

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Simulating the Functional Performance of Retort and Hotfill Flexible Packaging

by: *Jay Z. Yuan, Ph.D., P.E.*
Stephen DeHoff
Clinton A. Haynes

There is a growing trend toward flexible packaging most typically manufactured from polymer films and various laminate structures.

The primary driver behind the trend is ***sustainability***. A reliable rule of thumb is that the packaging system that delivers a product with the least total weight of packaging material is the most sustainable. The use of flexible films and laminates is growing because they represent less packaging material to deliver the same amount of product.

The trend toward flexible packaging for sustainability is not without challenges. It is apparent that a flexible pouch with 50 oz of detergent will not stack the same as a 50 oz bottle, and will probably require more corrugate for adequate strength and stability. Many life-cycle studies implicitly allow package performance to vary across compared options, beyond the base delivery of a given quantity of product in compared packages. Failure to account for performance differences can lead to questions about the accuracy of some life-cycle results. For example, a flexible pouch might be more prone to failure if dropped and harder for the consumer to pour doses without spilling.

However, the real-world truth is that decision makers have proven willing to accept performance variation in support of sustainability initiatives.

Figure 1: Examples of commercial retort & hotfill flexible pouch packaging

One of the most challenging applications for metalized flexible packaging is hot-filling and retort sterilization for liquid or low-stiffness food and beverage products (Figure 1). Both of these processes impose significant pressure and thermal loads on the package for an extended period.

There are a range of technical issues for retort and hot-fill applications that can arise in flexible packaging. Some of the most problematic are:

1) Inconsistent opening of the pouch prior to filling
2) Excessive deformation of the pouch after filling with hot product
3) Potential contamination/failure of the closure seal region as a result of liquid contamination
4) Rupture of the seal during retort due to internal pressure/overpressure differences

Any of the above scenarios may result in either packing line productivity losses or quality issues.

MODELING AND SIMULATION TO REDUCE RISK IN RETORT POUCH DEVELOPMENT

Stress Engineering Services broadened the applicability of our proprietary hot-fill and retort simulation software, BiPATH, to include flexible packages. This allows developers, manufacturers, and end users of these flexible packaging platforms for food and beverage applications to eliminate trial-and-error development in favor of a physics-based "design-by-analysis" approach. This approach can reduce development schedules and costs by 30% to 50% relative to a conventional development methodology.

EXAMPLE OF DESIGN-BY-ANALYSIS METHODOLOGY FOR RETORT AND HOT-FILL POUCHES

Figures 2 through 7 illustrate the modeling, simulation, and analysis of manufacturing, filling, and retort processing of a "stand-up" retort pouch.

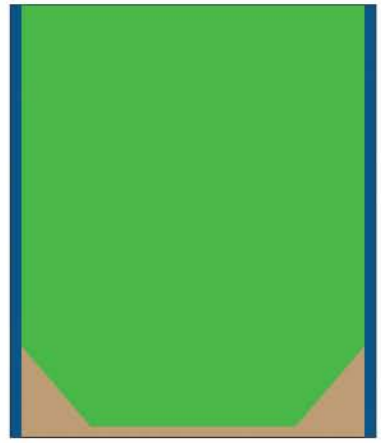

Figure 2: Illustration of a formed package with a gusset base, cut from roll-feed

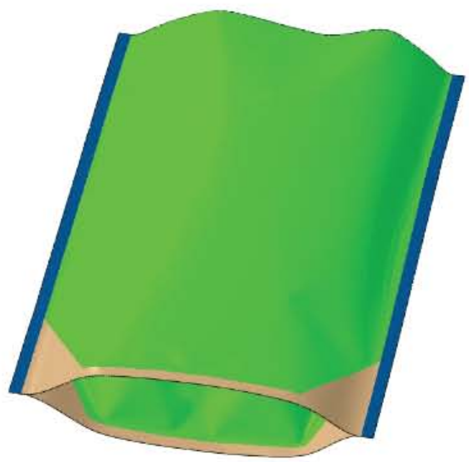

Figure 3: Pouch is opened immediately prior to filling

Figure 4: Simulation of pouch filled with liquid product prior to sealing and retort processing

Figure 5: Simulation of final closure heat seal and deformed shape of pouch, prior to retort

After being filled and sealed, the pouch and its contents are sterilized in a retort by heating it to a prescribed temperature for a specific time. A representative retort process (pressure, temperature, and time) is illustrated in Figure 6. The package and process must be designed such that the overpressure during the retort cycle reasonably follows the development of internal pressure in the sealed package. If the retort equipment control system allows the internal package pressure to become too large, the package may rupture. And rupture is not the only problem that can result from excessive internal pressure. At retort temperatures, the polymer components of the packaging film and the polymer/polymer seal will creep at an accelerated rate, resulting in permanent deformation of the package or seal damage.

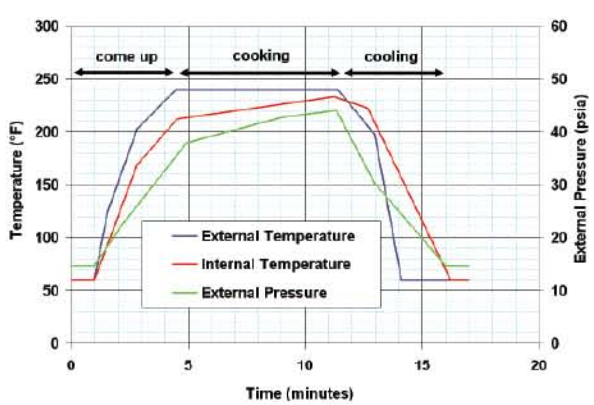

Figure 6: Typical retort temperature and pressure profiles

Figure 7 shows a stress contour plot of the pouch at the end of the cooking period. Depending on the retort temperature and pressure profiles, the pouch is normally at its maximum pressure at this point in the cycle, and the heat-sealed perimeter experiences the greatest stress. This is also where damage can occur due to material creep. Modeling, simulation, and analysis can be used to identify potential weak areas of the flexible pouch, specifically, leakage caused by seal damage or permanent deformation resulting from creep.

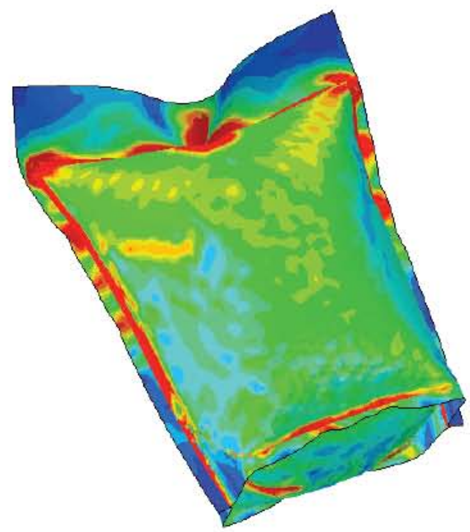

Figure 7: Stress contour plot of the pouch at the end of cooking period inside the retort

POWERFUL TOOLS FOR FLEXIBLE PACKAGE DEVELOPMENT

Stress Engineering has developed an efficient, physics-based approach for flexible hot-fill and retort packaging comprising modeling, simulation, and analysis. This approach enables film manufacturers, packaging suppliers, and OEMs to eliminate trial-and-error development by predicting the performance of new designs before manufacturing begins. Stress Engineering's method can also be used as a process-development tool, enabling simultaneous optimization of the process and pouch design and materials.

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Deepsea Vibration Monitoring

Stress Engineering's Subsea Vibration Data Logger (SVDL)

by: Kenneth Bhalla, Ph.D. and Daniel J. Kluk

As offshore drilling and production facilities are pushed to operate in deeper waters, the equipment used in these facilities is exposed to harsher environments. Moreover, as reservoirs with high pressure and temperatures are being developed, it is of the utmost importance that the integrity of each system used to drill and produce any field be maintained.

Given these concerns, accurate assessment of the present operating state and future life of equipment in these environments is essential for site safety and operation. Stress Engineering Services recently developed a data acquisition instrument, the Subsea Vibration Data Logger (SVDL), specifically to monitor dynamic structural response and fatigue in deepwater applications.

Figure 1: Subsea Vibration Data Logger designed by Stress Engineering for vibration and fatigue monitoring of deepwater drilling and production equipment; one ROV handle design is seen on the right end of the device.

Vibration in deepwater applications most often occurs in the form of wave-induced motions, vessel induced motions, vortex induced vibration, or flow induced vibration. The SVDL installs directly on subsea equipment in order to monitor these and other forms of vibration and to assess fatigue damage.

The unit is a 3.1 inch diameter cylindrical device that is 18.25 inches in length. Stress Engineering Services customizes SVDL clamping, mounting, and installation devices as suits the particular structure being measured

Figure 2: SVDL with a low moment-of-inertia clamp intended for installation on jumper lines and monitoring flow induced vibration

and the deployment method (surface installation, ROV installation, etc.). Figure 2 depicts an example of a low moment-of-inertia clamp developed for monitoring jumpers, which may be subject to flow-induced vibration and resultant fatigue damage.

Designed with a long battery life, low power consumption, and large memory storage, the SVDL operates in two states: long-term intermittent or short term continuous. In long term intermittent monitoring applications, the SVDL allows users to observe structural changes, like damage or wear, over a period of months. Short term continuous monitoring is for characterizing equipment changes over a specific time window lasting up to 3 weeks. A short-term sample case would be the need to measure flow induced vibration that occurs when adjusting the flow of fluid passing through a piece of equipment like a jumper.

As a device intended for deep sea applications, two SVDL design factors were of primary importance:

- Maintain high enough data resolution and accuracy to provide accurate and valid fatigue and safety information
- Design for unique use in the harsh deepwater environment

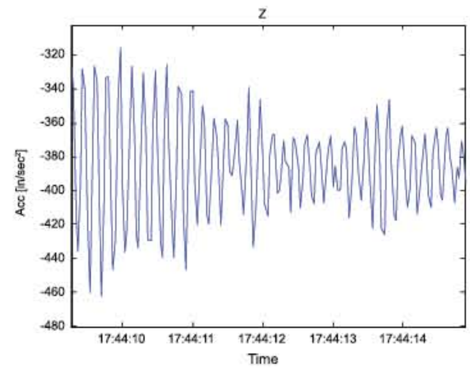
RESOLUTION AND DATA ACCURACY

Housed inside the SVDL unit is a high-quality tri-axial accelerometer, hard-mounted to the pressure housing end cap in order to maximize the stiffness of the device as coupled with the measured structure. The accelerometer is constructed using a state-of-the-art MEMS process to achieve a high degree of sensitivity and resolution. The device's analog sensitivity is 2000 mV/g, which translates into a digital sensitivity of 8,192 LSB/g in 16-bit mode or 2,097,152 LSB/g in 24-bit mode. The resolution is 0.35 milli-g, which provides an equivalent digital resolution of 3 LSB in 16-bit mode or 734 LSB in 24-bit mode. Measured signals pass through an aggressive low-pass analog filter prior to digitization using a high-resolution analog-to-digital converter. In addition to signal filtering, oversampling techniques are employed to maintain the desired high standards for digitized signal quality.

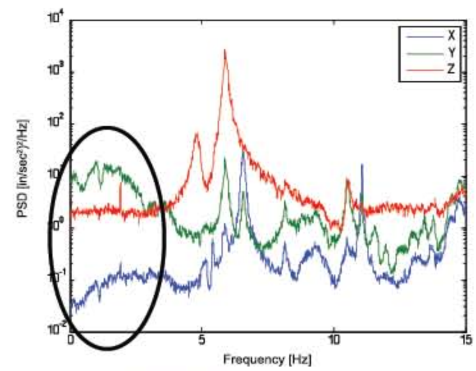
Stress Engineering Services designs each SVDL installation, which includes a data logger and clamping device, as a coupled system of low mass and high mechanical impedance. This ensures that the vibration signals collected by the logger are not distorted by the mechanical characteristics of the logger system itself, even at measurement frequencies of 50 Hz or greater, which are occasionally observed in subsea flow induced vibration scenarios.

DESIGNED FOR DEEPWATER LIFE

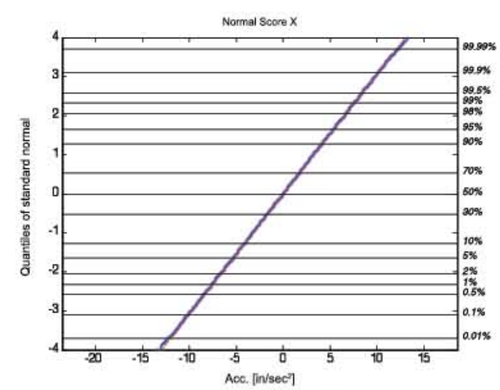
The SVDL has a depth rating of 10,000 feet in sea water. Its sensors and electronics are fully enclosed in a one atmosphere aluminum subsea housing with redundant o-ring seals at each closure. All exposed aluminum surfaces are hard-anodized, and the device is ported for nitrogen back-fill. This back-fill prevents the formation of moisture, which could potentially damage the internal electronics, within the device. In



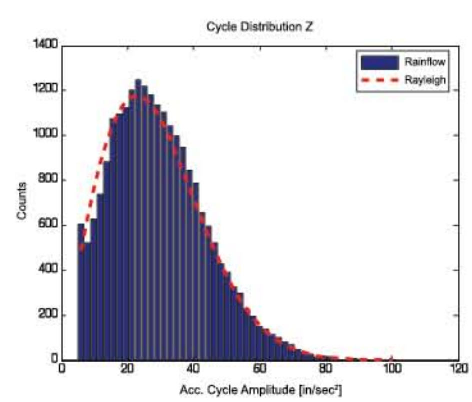
Waveform Analysis



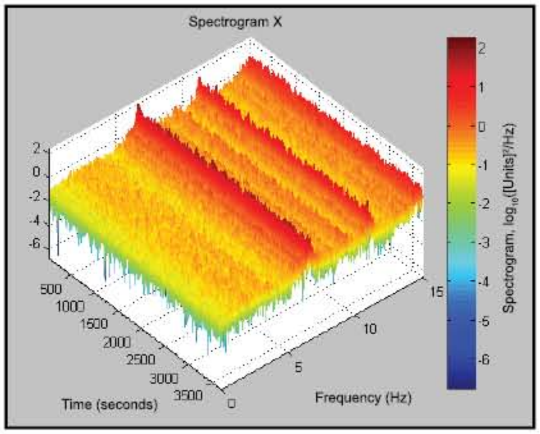
FFT/PSD of Acceleration



Gaussian Process



Narrow Bandedness



Stationarity of Signal

addition, there is a pressure relief valve to prevent over-pressurization in the unit, which could occur due to thermal effects imparted during pre-deployment operations.

Combined with prediction analysis to assess expected mode shapes and fundamental system frequencies prior to measurement and with proper data interpretation and reduction following measurement, Stress Engineering Services offers the SVDL as a customizable tool that improves:

- Operational safety
- Reduces risk
- Maximizes uptime and operational efficiency
- Improving overall upstream profitability

As a next step to support the development of the SVDL technology, Stress Engineering Services is presently in the process of developing a real-time fatigue monitoring system that will provide immediate assurance of operations; this system will be operational in Fall 2011.

Where accurate fatigue measurement and prediction is essential to the safety and continued operation of deepwater offshore drilling, the importance of developing application appropriate devices such as the SVDL can be the difference between safe continued operation and equipment failure scenarios.

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The Stress Engineering Services subsea vibration data logger (SVDL) was developed to service the need to collect high-quality vibration data for extended periods under increasingly stringent subsea environments.

APPLICABLE INSTALLATION SITES:

- Deepwater Drilling Risers
- Completion Risers
- Production Risers
- Flowlines
- Jumpers
- Manifolds
- Wellheads

IMPACT ON SITE:

- Safety improvements
- Risk reduction
- Maximization of equipment uptime
- Improved operational efficiency
- Improved profitability

SPECIFICATIONS:

- Depth rating: 10,000 feet sea water
- Exterior dimensions: 3.1" D x 18.25" L
- Mass: Less than 10 lbm
- Weight in seawater: Less than 6 lbf
- Environmentally sealed electronics: sensors and electronics fully enclosed in a one-atmosphere aluminum subsea housing with redundant o-ring seals at each closure
- Surface treatment: all exposed aluminum surfaces hard-anodized
- Back-fill capabilities: ported for nitrogen back-fill

When the Wrong Thing Fractures

Split Grade P110 couplings have become a persistent problem during high pressure fracturing operations in shale gas wells.

by: Michael G. Burns, P.E.

With remedial costs exceeding two million dollars in some cases, these failures have drawn attention across the industry. Our metallurgical engineers have worked with numerous manufacturers, casing distributors, and end users to perform dozens of failure analyses on split couplings.

The initial purpose of a metallurgical failure analysis is to identify the immediate cause of failure. Did it occur because of a manufacturing defect, unusually severe environmental conditions, mechanical damage or excessive loading? With the laboratory tools at their disposal—visual examination, metallographic examiation, scanning electron microscopy, hardness testing,and mechanical testing—Our metallurgical engineers have the right tools to sort out these failures.

When Good Couplings Go Bad

Even more vexing is the much larger number of failures that have occurred in P110 couplings that were completely satisfactory in heat treatment and manufacture. Most of these fall into the general category of environmentally assisted cracking, either sulfide stress cracking or hydrogen stress cracking. Sulfide stress cracking in sour wells is relatively well known and, for this reason, oil and gas operators generally avoid the use of Grade P110 in highly sour wells. However, less severe environments can also crack highly stressed P110 couplings even when the hydrogen sulfide content of the produced fluids is very low. This phenomenon is termed hydrogen stress cracking, although it may also be known as hydrogen embrittlement cracking.

Manufacturing Defects

Some failures have been caused by a range of manufacturing defects. Splits may initiate at seams, which are a type of forming defect that is created during the shaping of the steel into a tube. Quench cracks may occur during heat treatment and cause a catastrophic failure as soon as the coupling is pressurized. The most common type of manufacturing defect, however, appears to be incorrect heat treatment.

Since P110 is a quenched and tempered grade, it must be heat treated by austenitization (heated to a high temperature), quenching (rapid cooling, usually in water), and tempering (reheated to an intermediate temperature). Failure to perform any one of these steps correctly results in steel that fails to exhibit the yield strength, tensile strength, or toughness required of Grade P110.

Why My Couplings?

Hydrogen stress cracking, like all forms of environmentally assisted cracking, is dependent on three factors- the aggressiveness of the environment, the susceptibility of the material, and the stress level. These interact in a complex manner. If any one is unusually high, that reduces the minimum severity of the other two required to initiate cracking.

The Stress

Because API 8-round and buttress-thread connections are tapered connections, power-tight make-up subjects the coupling to relatively high circumferential stresses. Add the effects of high internal pressures during a fracturing operation, and the coupling material is stressed nearly to its limit. Under such high stresses, a slight increase in the susceptibility of the material or the aggressiveness of the environment can be enough to cause an axial split in a P110 coupling.

The Material

The susceptibility of quenched and tempered steels like Grade P110 to hydrogen stress cracking increases with hardness and strength. Unfortunately, with the proliferation of "high-collapse" grades, there has been a corresponding increase in the typical yield strength of Grade P110 casing and couplings—and an increase in the number of couplings that fail due to hydrogen stress cracking. Hydrogen stress cracking failures of Grade P110 couplings have occurred overwhelmingly in couplings with a yield strength in the upper quarter of the specified 110-140 ksi yield strength range.

Another factor that can increase the susceptibility of Grade P110 couplings to hydrogen stress cracking is the presence of mechanical damage. Tong marks and other handling damage can introduce residual stresses and locally cold work the steel, increasing its susceptibility to hydrogen stress cracking. As a result, many hydrogen stress cracking failures initiate at tong marks or similar mechanical damage. Operators should be very cautious when using even lightly damaged couplings in casing strings that will be subjected to fracturing pressures.

The Neighborhood

The environment can also have a significant effect, even if hydrogen sulfide is not present. The severity of the downhole environment is also a factor. The use of inhibited hydrochloric acid as a fracturing fluid is particularly problematic, but hydrogen stress cracking failures have also occurred with relatively benign fracturing fluids. One factor is that the casing may be installed and exposed to acidic produced brine for weeks before the fracturing operation. During this time, hydrogen generated by corrosion can enter the steel and build up at the relatively high downhole temperatures. When the fracturing operation commences however, the temperature of the casing may drop quickly, cooling from a moderately elevated temperature where hydrogen is more soluble and more mobile in steel to near ambient temperature, where hydrogen is less soluble and more likely to cause cracking. As a result, many coupling failures have occurred during the initial cooling and pressurization of the casing at the beginning of the fracturing operation.

What Next?

The range of solutions is relatively limited. To improve the resistance of the material, coupling manufacturers may choose to limit the yield strength to less than 125 ksi. This is feasible even for high-collapse casing, because the collapse resistance of a casing string is controlled by the properties of the casing, not the properties of the couplings.

It may be possible to develop proprietary 110 ksi yield strength grades with an increased resistance to hydrogen stress cracking, similar to sour service grades, although the testing methodology for such grades has not been fully standardized.

For critical wells, preventive measures might include the use of either premium connections or sour-service grades for coupling stock. Straight-threaded premium connections have an advantage in that the hoop stresses from make-up are typically very low, which reduces the driving force for hydrogen stress cracking. Also, operators should carefully consider the prudence of fracturing through Grade P110 with inhibited hydrochloric acid or re-using couplings with noticeable tong marks.

For more information, see "Analysis of High-Collapse Grade P110 Coupling Failures" by Michael G. Burns, P. E. and W. M. Buehler, presented at MS&T 2010, Houston Texas, October 17-21, 2010.

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Deepwater Response to Underwater Pipeline Emergencies – Part III

Post Site Integration Tests and Design Upgrades

by: Adalberto Silos, P.E.
Armando Rebello, P.E.
Ray Ayers, Ph.D., P.E.

Deepwater Response to Underwater Pipeline Emergencies (DW RUPE) is a Joint Industry Program (JIP), created in 2005 to develop a solution for the repair of deep water pipelines and flowlines in water depths up to 10,000 feet.

The DW RUPE consortium's goal is to be prepared with an inventory of tools and equipment that will help bring the nation's fuel resources back to normalcy within a short period of time and at a fraction of the cost traditionally experienced during emergency periods.

Our last article on DW RUPE appeared in the 2009 issue of StressTalk. That was prior to us conducting the project Site Integration Test (SIT), to ensure that the individual components were working well when combined into a pipeline repair system.

For damage to be repaired, often the pipeline must be lifted from the seabed for cleanup, external coat and weld seam removal, and cutting (if the repair requires replacing a damaged section).

For a typical section repair, DW RUPE utilizes four symmetrically placed frames—the indexing base frames (IBFs) and the pipeline lifting frames (PLFs).

The SIT (Figure 1) highlighted a series of modifications related to the hydraulic system of the IBFs and PLFs that will improve the reliability of the system.

The focus of this article is the grapple device (Figure 2), an articulated device whose function is to pick a pipeline section from the seabed and lift it so it can be cleaned, cut, aligned and released after repair completion.

Currently, the grapple is actuated by a single rod standard double-acting hydraulic cylinder (Figure 3). This cylinder type provides a power stroke in both directions, but displaces different volumes of hydraulic fluid due to the different piston areas in contact with the

Figure 1: DW RUPE SIT setup at the Stress Engineering Waller testing facility

Figure 2: Grapple in action during SIT

hydraulic fluid (Figure 4). This design requires volume compensation either at the IBFs and PLFs, or on the ROV system. The cylinder design also has physical vulnerabilities since punctures or leaks in the hydraulics would cause the grapple to fail and the pipe to be dropped. It also does not support the option of an ROV mechanical override if the hydraulic system becomes inoperable.

The proposed modification (Figure 4) will retain most of the mechanical grapple components, while the hydraulic cylinder will be replaced by a mechanical system composed of an ACME thread with bronze nuts and actuated by a hydraulic motor. The free end of the mechanism will be provided with an ROV bucket so that, if the hydraulic system fails, the grapple will maintain its grip on the pipeline until the ROV mechanically turns the buckle.

Table 1 summarizes the changes and illustrates the achievements related to these modifications. DW RUPE also implemented a ***continuous improvement program*** to continuously update its equipment as well as its pipe specific consumables, clamps, and connectors, ranging from 10-inch to 24-inch and capable of conducting repairs to 10,000 ft water depth.

The four grapples will undergo modifications in March 2011.

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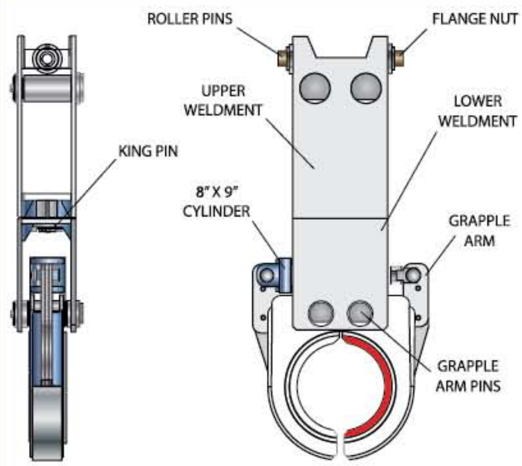

Figure 3

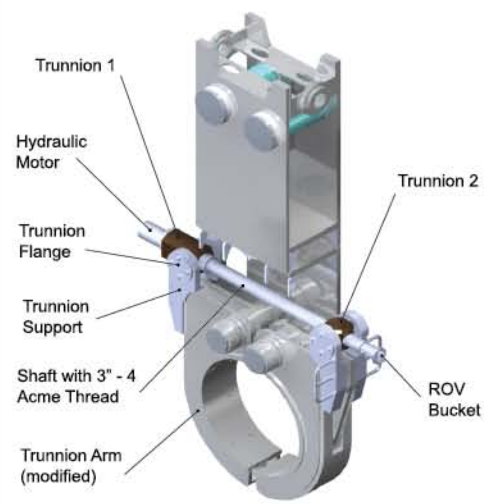

Figure 4

Table 1 - Design Comparison

Required Improvement	Existing Design	Proposed Design
Eliminate the need for an accumulator	Single rod standard double acting cylinder. Accumulator necessary to avoid hydraulic locking of system.	Acme thread and a bi-directional hydraulic motor. No accumulator required. Selected acme thread is self locking
Override in case of hydraulic system failure	No override available	ROV bucket provides mechanical overriding for opening and closing of the grapple arms
Locking of grapple arm in case of hydraulic system pressure drop		Selected acme thread is self locking

Evaluating Fitness-for-Service of Damaged Equipment

by: Joe Frey, P.E.
Peter Carter, Ph.D., P.E.
Mike Guillot, Ph.D., P.E.

FFS EVALUATIONS

An all too familiar scenario in power plants is one in which an inspection finding occurs late in an outage and consequently, the return to service date may need to be postponed to allow time for corrective action. Historically, cracks or thinned spots were typically repaired without question. In contrast to this, the use of a fitness-for-service evaluation in this scenario has long been common practice in the petrochemical industry. Competition forces drove that industry to run with lower safety factors and more stringent engineering evaluations early in its development. The regulated electric utility industry, however, allowed for costs to be passed on to the customer, and it was common practice to return boilers to service in "like new" condition. With the deregulation of the electric utility industry, the need to be able to run the unit safely and reliably until the next outage replaced the requirement to do so until the scheduled retirement date. Consequently, the use of the fitness-for-service (FFS) standards API 579-1 / ASME FFS-1 is increasing in the power industry. This evaluation can result in significant savings in costs and time while maintaining safety.

The National Board Inspection Code (NBIC) published by the National Board of Boiler and Pressure Vessel Inspectors provides standards for installation, inspection, and repair and/or alteration of boilers, pressure vessels, and pressure relief devices. In recent years, the NBIC added references to the use of FFS methods found in FFS-1. Referencing of these methods was significant because it signaled that the owner was being allowed to evaluate a damaged condition instead of automatically restoring the component to like-new condition. This option represented a significant savings to the owner at a time when deregulation was fueling competition. The trend continues and fitness-for-service evaluations for situations not currently included in FFS-1 are being conducted in the same methodical approach as FFS-1. An example of such is the recent incident involving the late discovery of three broken main steam piping spring supports and a fast approaching return to service date.

EVALUATION OF DAMAGED PIPE SUPPORTS

Stress Engineering Services was recently requested by the operator of a large industrial plant to provide a FFS disposition for the main steam pipe at one unit. During a scheduled maintenance outage at the plant, inspectors had discovered that three variable-spring pipe supports on the steam pipe riser had cracked springs. The unit was scheduled to return to service about one week after these failed components were discovered; that is, there was insufficient time to replace the pipe supports. The plant operator urgently needed to know whether the unit could safely be returned to service with the cracked springs supporting the pipe and, if so, what the risks and consequences of further failure

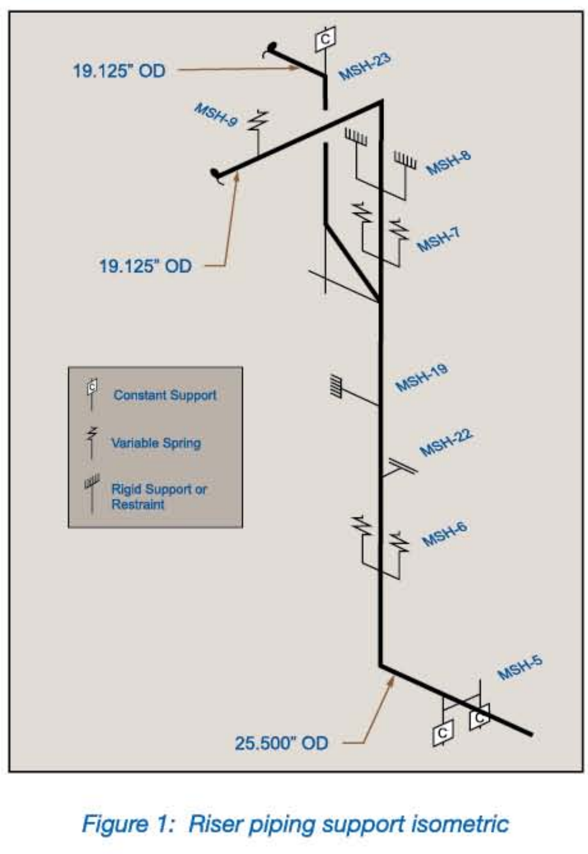

Figure 1: Riser piping support isometric

would be. If the damaged springs could safely remain in place for the interim, they would be replaced during the next scheduled outage several months in the future.

As is often the case in FFS assessments, the plant operator contacted us for immediate analysis and recommendations. Our personnel quickly mobilized for traveling to the plant with the appropriate equipment. We also immediately began to prepare a pipe stress model based on information from the operator. A finite element analysis model of the batwing welded attachment was also begun in preparation for addressing any loading and remaining life concerns that might develop as a result of knowing the actual pipe support loads.

The main steam piping under consideration consisted of a 25½" OD main run with 19" branches at both the boiler and turbine ends. Three main steam spring supports (MSH-6 south and MSH-7 north and south) were determined to have cracked springs. Figure 1 shows the main steam pipe routing and pipe support locations.

Once on site, we installed strain gages on the six hanger rods for supports MSH-6, -7, and -8 to measure strains in the riser supports. A typical strain gage installation is shown in Figure 2. The strains were measured as each pair of rods was unloaded. Support loads were calculated based on actual hanger rod diameters and measured strains. Hanger load data were used in the pipe stress model to calculate loads on the supports and piping. Pipe wall thickness was measured using ultrasonic testing (UT) and actual pipe wall thicknesses were used in the evaluation.

We determined that the cracked springs were carrying lower loads than designed and lower than equivalent springs that were not cracked. Analysis indicated that, at the cold condition, load was being transferred to hanger MSH-23 located above the rigid support. At the hot condition, the load shifted to hanger MSH-5, the first pipe support on the lower horizontal run below the riser. We also determined that hanger MSH-5 bottoms out after 8½" of downward thermal growth. The pipe is expected to grow about 12" downward; consequently, the remaining thermal growth beyond the capacity of hanger MSH-5 is forced upward, thereby reducing the load on the riser pipe supports in the hot condition.

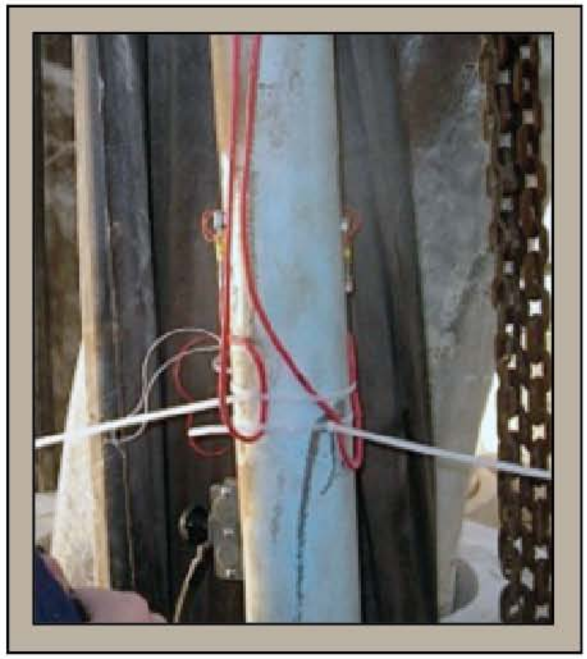

Figure 2: Strain gages installed on rigid support MSH-8

Although this was not the original design, it had the beneficial effect of countering the loss of support at the cracked springs. Further analysis would be required to determine the long term effect on the piping at hanger MSH-5.

Calculated stresses for the pipe and connection welds were determined to be below Code allowable stress. We concluded that the cracked springs did not have a significant effect on the remaining life or risk of failure of the main steam pipe.

Based on our recommendations, the operator returned the unit to service on schedule. After the subject pipe was stabilized at its operating temperature of 1000°F, loads were again measured in the field for the same three pipe supports. These hot loads were then compared to the Code stress model results to further calibrate the model. Predictions were sufficiently close to measured loads, and the original conclusions remained unchanged. In addition, we prepared recommendations regarding replacing the cracked springs in the future, balancing the loads, and possibly redesigning the support system.

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Improving Plant Mechanical Integrity

through Integrity Operating Windows and Corrosion Vulnerability Assessments

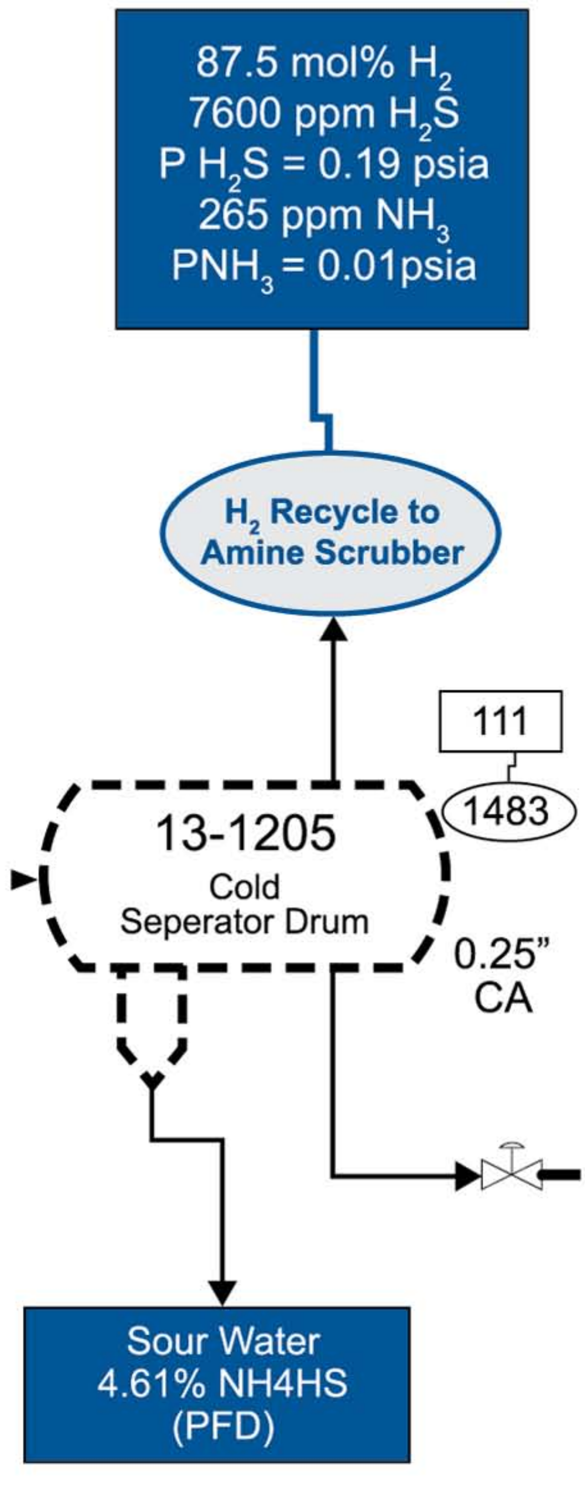
by: Alphonse W. Hegger, Jr., P.E.

Integrity Operating Windows (IOWs) refer to process or operational control limits that are required to support the mechanical integrity of equipment used in the refining and chemical process industries. The intent is to identify plant operating thresholds, which if exceeded, would result in an unacceptable risk of a process containment breach. IOWs take into consideration the existing equipment metallurgy, anticipated damage mechanisms, rates of deterioration, review of equipment inspection history, possible fluctuations in process parameters and transient conditions during startup and shutdown.

Common refinery IOWs include, but are not limited to:

- **Composition of purchased crude oil or other feed streams**
- **Maximum furnace tube skin temperatures**
- **Water boot chemistry, as controlled by water wash rate or chemical addition**
- **Maximum (or minimum) process temperatures**
- **Water/moisture content limits**
- **Maximum hydrogen partial pressure**
- **Chemical or water injection parameters**
- **Piping velocity or shear stress limitations**
- **Procedures to address transient conditions during startup or shutdown**

Not all process parameters necessarily require IOWs. Only process parameters which affect the occurrence or rate of a specific damage mechanism are possible candidates for the application of an IOW. IOW operational parameters must be measurable and measurements must be performed at some defined interval and trended with time. The development of IOWs requires



prior completion of a detailed materials and corrosion assessment which identifies vulnerability gaps within the mechanical integrity program.

A materials and corrosion assessment uses a Corrosion and Materials Diagram (CMD) as a roadmap, modified with more detailed temperature surveys and key process information. The CMD is a process flow diagram annotated with materials of construction and corrosion mechanisms, in addition to standard operating conditions. The CMD is then divided into smaller "corrosion loops" that have similar metallurgy, process conditions and anticipated damage mechanisms. The materials and corrosion review is typically completed at a P&ID level with supplemental tabular information associated with specific equipment and piping systems. The tabular information includes equipment or line number, ASME/ASTM materials of construction, heat treatment, prevailing operating temperature, insulation, corrosion rate, nominal corrosion allowance, potential damage mechanisms and key process information.

Unlike mechanical reliability models which use equipment-based logic, this assessment uses process-based logic that is understandable by all refinery personnel. Once completed, the materials and corrosion assessment highlights equipment which may require supplemental or more frequent inspection to manage integrity, and facilitates the development of IOWs. Most of the data required for the development of IOWs is also required for execution of risk based inspection (RBI). Once in tabular form, the data can easily be imported into an RBI program. RBI refers to the work process which prioritizes equipment inspections on the basis of risk, where risk is equal to the product of (failure frequency) x (consequence).

The cross functional team required for the corrosion and materials assessment and development of IOWs includes the following:

- Metallurgist or Corrosion Engineer: defines the corrosion loops, identifies potential damage mechanisms, estimates corrosion rates

- Inspector: may modify corrosion rates based upon actual history, validates potential damage mechanisms based on equipment condition history, identifies inspection techniques that are applicable to the specific damage mechanism under evaluation

- Process Engineer: assists in validating process components (i.e., hydrogen partial pressure, sulfur, nitrogen, temperature profile, water boot data, etc.); identifies areas of process control difficulty (this information is also critical to future RBI work)

- Operations Specialist: assists in capturing current process operating limits (existing IOWs), alarm points, water/chemical injection points, and other relevant laboratory data; identifies startup lines (intermittent use) and additional areas of vulnerability that may not be detected by tech service personnel (i.e., vibrating piping, leak history, instrument sensitivities)

- Piping Designer: formalizes the modified CMDs and P&IDs into standard drawings.

In addition to facilitating the development of IOWs and the execution of RBI, the formalized drawings and supplemental tabular information serve as basis for training operators and inspectors.

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Preparing for API 6A Annex F Testing: What you need to know

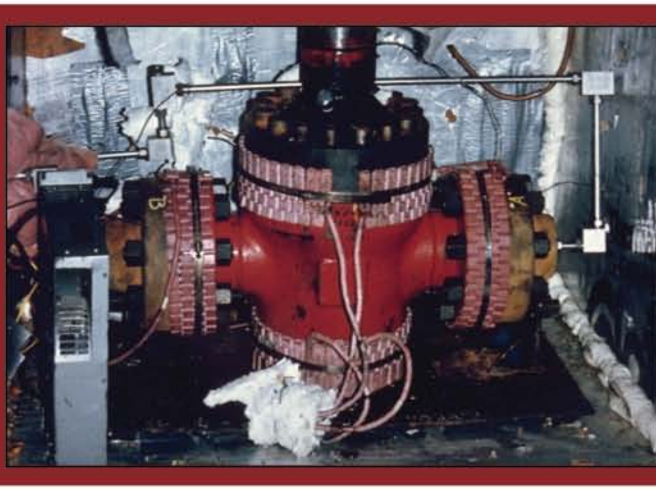
by: Scott Wharton, P.E.

The stated purpose of API 6A (ISO 10423) is an "international standard specifying requirements and giving recommendations for the performance, dimensional and functional interchangeability, design, materials, 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 Specification 6A – Specification for Wellhead and Christmas Trees Equipment, October 2010) The standard encompasses a wide variety of equipment including: wellhead equipment, connectors and fittings, casing and tubing hangers, valves and chokes, and other equipment.

One of the items overlooked at the start of project or sale is the testing requirements contained within API 6A. The opening statement in Annex F of API 6A states: "This annex provides design validation procedures for qualification of equipment specified by this international standard, which shall be applied if specified by the manufacturer or purchaser." That statement opens up the discussion for testing to the requirements of Annex F at the time of the sale of the equipment. Given the cost and man power needed to perform the required tests, all parties need to be aware of the challenges associated with testing to API 6A Annex F to validate that the design meets the functional and technical specifications for the equipment.

The annex requires pressure, temperature, and open/close cycling testing to help validate the design of wellhead equipment. Each of these tests can add challenges to the completion of the Annex F requirements.

Pressure testing is usually seen as the simplest of required testing , but even it has some pitfalls that need to be reviewed prior to the start of the testing program. Does the equipment need gas or hydrostatic testing? When is leak detection required and from what locations on the equipment? How is leak detection performed in accordance to the standard? What are the requirements for pressure stabilization during elevated temperature testing? The annex addresses some of these questions, such as gas testing is required for equipment rated to 10,000 psi (69.0 MPa) and above, but often purchasers will require gas testing on equipment below 10,000 psi. If gas testing is required, then leak detection also becomes a requirement. Again,



"Annex F of API 6A provides design validation procedures for qualification of equipment specified by this international standard, which shall be applied if specified by the manufacturer or purchaser."

this adds to the complexity and cost of the testing. Last with all testing, safety is the foremost requirement. In a worst case scenario, how do you contain the energy release during a gas test?

Temperature testing provides a list of items that need to be determined prior to any test program. What temperature range is required/needed for the test program? How is the temperature going to be applied to the equipment? At what location is the official temperature of the equipment recorded from?

Of these questions, the one that most often gets debated during the testing program is the location of the official thermoprobe on/in the test equipment. The annex states: "The temperature shall be measured in contact with the equipment being tested and within ½" (13 mm) of the through-bore, where applicable, and within ½" (13 mm) of the surface wetted by the retained fluid on other equipment." Placement of the thermocouple needs to be discussed prior to the testing program will all parties, including manufacturer, purchaser, and third-party witness. Each party may interpret the location differently.

The open/close cycling testing for valves, chokes and other equipment adds complexity to the testing program. If the valve or choke is manually operated, then the testing lab must devise a way to actuate the equipment in a safe and reliable manner. The annex also requires the determination of torque/force required to open/close the equipment. The addition of torque cells or load cells to an actuator requires forethought and possible additional test fixture design. Further, the actuation method must be used during maximum and minimum temperature/pressure tests. Can the method of actuation handle the temperature changes or does the actuation need to be isolated from the equipment?

Stress Engineering Services can help prepare and test equipment to API 6A Annex F. We have been performing Annex F testing for over a decade and are extremely knowledgeable about the challenges of testing to this standard.

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Strain Gages
in Hard-to-Reach Interior Diameters

by: Kurt Vandervort, Ph.D., P.E.

For over 20 years Stress Engineering Services has served the Oil & Gas industry's needs for testing and analysis.

In that time, there has been a number of industry changes that have introduced new challenges and requirements to the testing environment including:

1. Performance requirements for downhole equipment and tools have dramatically expanded.
2. The additional loads on the handling equipment and on the equipment being handled, typically tubulars, due to increasing well depth.

Often, tubular handling equipment grips on the OD of the tubular, making it impractical to attach sensors for high-quality measurements on the OD. Strain gages are very efficient and versatile, but they are fragile and the wires connecting them to data-acquisition systems are also fragile. Applying strain gages on the OD of a pipe that is being supported by tubular handling equipment is often not a practical option. To solve this problem, we have developed methods and tools for applying strain gages on the ID of a wide range of tubulars.

Becuase of ever-increasing load requirements, concerns over drill-pipe stresses and handling have increased greatly. In 1959, Spiri and Reinhold published an equation that has become the cornerstone used to model drill-pipe/slip interaction. However, recently this equation has come under increased scrutiny. To better understand and accurately measure the strains on drill pipe during loading/holding in slips, we developed a methodology and system for applying strain gages on the ID of drill pipe. This methodology has been successfully applied to a range of tubular sizes from 3" ID to more than 15" ID and beyond. This methodology has allowed laying strain gages or rosettes inside the pipe as deep as 20 ft from the end of the pipe.

Many of these test programs we completed required the strain gages to be laid in an array on the ID of the pipe with consistent and known spacing. Our method has been used for laying individual gages at a specified depth and orientation, as well as for pairs at the same depth and 180° apart, and equally spaced rings of 3, 4, 5, 6, and 12 rosettes. Furthermore, multiple symmetric rings of gages have been laid inside the same pipe with the depth of each ring of gages controlled to within approximately ⅛" of the specified distance.

After installation, these gages have then been tested to strains that far exceed the yield strain of the pipe. Instrumented pipes have been loaded multiple times with little or no degradation in strain gage performance. This method has proven to be reliable and fairly broadly applicable.

The extent of local surface preparation inside the tubular has varied depending on the application. Rosettes have been affixed to machined IDs where the actual dimension was critical. In other applications, the entire ID has been lightly sand-blasted so that there was a generally clean pipe surface. Some local surface preparation (cleaning) has been performed, also completed deep inside the pipe and well beyond arm's reach. In other applications, gages were applied individually so that the surface preparation was only local.

In all types of applications, we have had good success applying uniaxial strain gages or rosettes inside tubulars and having them survive extreme test conditions while providing the desired data.

The photographs shown below are example arrays of strain-gage rosettes that were laid on the ID of various pipes. In these cases, the area of interest was the interaction of either drill pipe slips on drill pipe, or spiders handling heavy casing strings. Other applications have included monitoring the strain conditions on a pipe through a packer, while supported by an elevator, and during handling with special handling tools.

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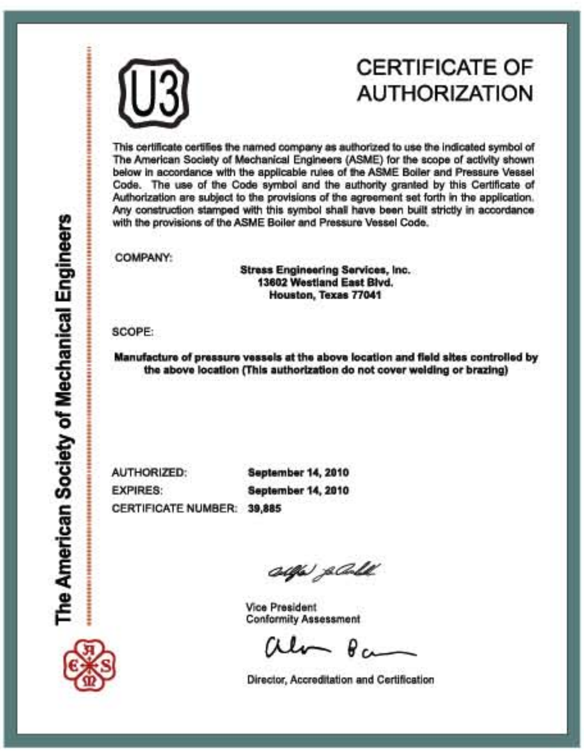
Stress Acquires ASME "U" / "U2" / "U3" Stamps and National Board "R" Stamp

by: Chip Collerain, P.E.

Stress Engineering Services has a long history of engineering, analyzing, and supplying advanced pressure vessels and systems to a wide variety of industries. In recent years, Stress has pioneered the engineering development of special pressure vessels for cutting-edge collapse test systems. These have been installed in various pipe mills and other facilities around the world and are capable of addressing the latest requirements of standards such as API, ASME, ISO, PED, etc. for operating pressures as high as 30,000 psi.

Although a number of Stress engineers currently serve on the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) committees, Stress had not previously sought certification that would allow it to serve as the Manufacturer of Record for pressure vessels. In view of the expanding needs of our clients for advanced vessel engineering, Stress has now sought and obtained full industry certification.



The American Society of Mechanical Engineers

U3

CERTIFICATE OF AUTHORIZATION

This certificate certifies the named company as authorized to use the indicated symbol of The American Society of Mechanical Engineers (ASME) for the scope of activity shown below in accordance with the applicable rules of the ASME Boiler and Pressure Vessel Code. The use of the Code symbol and the authority granted by this Certificate of Authorization are subject to the provisions of the agreement set forth in the application. Any construction stamped with this symbol shall have been built strictly in accordance with the provisions of the ASME Boiler and Pressure Vessel Code.

COMPANY:

Stress Engineering Services, Inc.
13602 Westland East Blvd.
Houston, Texas 77041

SCOPE:

Manufacture of pressure vessels at the above location and field sites controlled by the above location (This authorization do not cover welding or brazing)

AUTHORIZED: **September 14, 2010**
EXPIRES: **September 14, 2010**
CERTIFICATE NUMBER: **39,885**

Vice President
Conformity Assessment

Director, Accreditation and Certification

In September of 2010, Stress received Certificates of Authorization from the ASME Code and the National Board of Boiler and Pressure Vessel Inspectors Code to manufacture and repair pressure vessels that are fully certified to be in conformance with these respective codes. Specifically, Stress now holds BPVC Section VIII, Division 1 ("U"); Section VIII, Division 2 ("U2"); and Section VIII, Division 3 ("U3") Stamps from ASME; and a Repair and Alterations ("R") Code Stamp from the National Board.

These stamps are the internationally recognized authority for pressure vessel manufacturing and are normally required by law in the U.S. for manufacturing pressure vessels. Although Stress does not routinely manufacture industrial equipment or pressure vessels, Stress has been intimately involved with its clients in all phases of pressure vessel manufacturing for many years. Our pressure vessel services include project management, design calculations, and analysis (including FEA and fracture mechanics). For existing equipment, we have long provided fitness-for-service evaluations for vessels and systems damaged by fire, corrosion, fatigue, etc. Coupled with this depth of practical experience, Stress can now offer our clients the added level of confidence that the Code Stamps afford.

While being certified for the "U" and "U2" stamps is noteworthy, Stress's "U3" stamp (for ASME Division 3 vessels) is a major accomplishment. This stamp, currently held by only 33 other entities around the world, will open up the potential for Stress to manufacture code-stamped collapse test vessels and high-temperature, high-pressure (HPHT) test and process vessels that are in increasing demand today.

The "R" stamp from the National Board provides Stress's clients the ability to complete a certified repair or re-rating of an existing code-stamped pressure vessel. This allows our clients to extend the service life and expand the service capabilities of existing vessels.

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