How Nondestructive Test Methods Help Prevent Failures
In Exploration and Production of Oil and Gas

by:

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Abstract

Today’s oil and gas wells are high temperature, high pressure, highly deviated, pushing tubular goods (casing, drill pipe and tubing) to their maximum limits. Sophisticated NDT equipment is required to provide greater accuracy for the discrimination of defects that exist on the internal and external pipe surfaces. The American Petroleum Institute (API) and International Standards Organization (ISO) continue to joined forces merging industry standards to provide a worldwide consistency of written specifications and recommended practices for the manufacturing and use of tubular products. Harsh drilling environments and extremely technical drilling practices are driving tubular products beyond their original designed limits. Quality Control and Quality Assurance depend greatly on “Nondestructive Test Methods” to know true dimensions to validate product to specifications.

The industry has maintained its tradition requiring inspectors to be certified to ASNT TC-1A or equivalent. Several test methods are employed as stand alone or in unison to complement each others strengths with the most common being electromagnetic, magnetic particle, ultrasonic, eddy current, gamma-ray and dye penetrant. Nondestructive testing is very important and economical in risk management programs to eliminate the potential of burst and collapse conditions on the more stringent string designs avoiding major disasters while providing engineers and designers with documentation and traceability.

Introduction

Exploration and the Production of hydrocarbons is the most important task man does today, without crude oil being processed to run homes, cars, big trucks, trains, ships, hospitals, manufacturing facilities, countries and so on, it would be a very simple world. Testing is performed on all products to be use in critical applications to know its condition at that moment in time. Before pipes are placed into service to perform without failure the test results are reviewed to reduce risk and manage the asset worth millions of dollars. In the beginning oil and gas wells were drilled at depths of 58 feet to a few thousand total vertical feet, today the average land rig is 10,000 feet TVD (Total Vertical Depth) with new technology being able to reach out 4,000 to 8,000 feet as the industry calls it “Extended Reach Drilling” in the horizontal direction from a single well site connecting multiple pay zones. In a case history from East Texas a shale type well has been completed with a 4,487-foot horizontal leg containing 14 stages currently producing gas at 19 million cubic feet per day.

Offshore drilling is really pushing technology making very complicated completions and blowing production rates through the sky. As the decisions for exploration of more remote and challenging environments rise so does the risk and demand for tougher drilling equipment requiring drilling rigs to push pipe to perform at extreme levels in many cases. Various types of drilling platforms to drill ships are put to work around the world. A semi-submersible drilling rig is on location about 84 miles west of New Plymouth in the Taranaki Basin in water depths of 1083ft to target oil in the Cretaceous North Cape reservoir in underlying Waimui sandstones at a total depth of 11,700ft. Other areas like the Gulf of Mexico have discoveries such as the Great White field, Silvertip and Tobago are targeted for the extreme production rates. Tobago is in 9,600ft of water and will set a record for the world’s deepest subsea completion. Other new discoveries as far offshore as 200 miles in 8000ft of water will be producing up to 35 wells over the life of the field that expected to produce at rate of 100,000 barrels of oil equivalent per day.
Drilling

First the Geologist determine where to drill and how deep the well will be, then the Drilling Engineer will design a means to get there and finally a Drilling Contractor will begin drilling. All projects are very expensive when everything goes right and if something goes wrong can become so expensive companies will end up bankrupt. Pay zones are reached by connecting pipe call OCTG (Oil Country Tubular Goods) to reach from the surface down to the oil and gas. Casing are pipes which have large outside diameters and Tubing is pipe with a smaller outside diameter and thinner wall thickness able to fit inside of casing used to flow or bring to surface the Oil and Gas. Casing comes in long lengths averaging 40 feet long with threads machined on each end to be connected onsite forming one very long pipe. Surface Casing is 18” to 24” in diameter with Intermediate Casing being 7” to 16” in diameter. Tubing has a shorter average length only 30 feet long with threaded connections and smaller diameters of 2 3/8” to 4 1/2”.

Many steps are required in drilling a well, once a Rig has move onto location that area is known as the well site. Breaking ground will begin with “Open Hole” drilling, meaning no protection or casing is in place to support the earth from caving in. Drill Pipe is the work horse and is designed robust to rotate the “Drill Bit” cutting away the earth, removing dirt, sand and rock “Making Hole” down to the area or layer hopefully containing oil and gas. As certain depths are reached the drill pipe is “Tripped” (removed from hole) then Surface Casing is installed and cemented in place to prevent the hole from collapsing and fluids from exiting into the surrounding environment. The drill pipe is returned to making hole, and then Intermediate Casing is cemented in place to protect precious resources like water aquifers to remain isolated from the drilling activities. Drilling mud is constantly being pumped and circulated to cool the drill bit and carry away cuttings as drill pipe continues to drive the bit deeper.

Once the TD (total depth) has been reached the drill pipe is removed so production casing and tubing can be installed to provide flow and pressure control. The rule of thumb on pressure is it increases by 1 lb/sq. inch (psi) for every foot drilled deeper, when a well has been drilled 6,000 ft, expected pressure will be around 6000psi, with so many unknowns, well blowouts and explosions may occur when higher pressures than anticipated are encountered exceeding the design of the well or in most cases having components fail when most needed.

Drilling deeper wells onshore and offshore necessitate advances in technology to design hoisting equipment to handle ultra long and heavier drilling, casing and production strings. Minimum cross-sectional areas and stress concentration points need to be evaluated for load bearing members. Many obstacles must be overcome and challenges must be met in order to successfully and safely make hole.

Without pipe, drilling a well would not be possible so addressing the importance of good quality, proper usage, care /handling and defect free material should always a part of the risk management program.

API specifications govern all areas of the drilling and producing of wells, specifications were written to document drilling practices, to specify proper equipment and to recommend to its industry how to be safe and efficient when searching for oil and gas. API has a long list of books that can be found at www.api.org/compositelist for every part of the industry such as Offshore Cranes in document 2C, Drilling and Well Servicing Structures (4F), Casing and Tubing (5CT, 5A5), Drill Pipe (5DP, Spec 7, 7G), Line Pipe (5L), Wellhead and Christmas Tree Equipment (6A), Drilling and Well Servicing Equipment (7K), Drilling and Production Hoisting Equipment (8A), Downhole Equipment - Packers and Bridge Plugs (11D1), Pumping Units (11E) and more.

Safety checks are part of each day, along with contingency plans to have multiple safety systems in place for quick closing off of the well bore to minimize damage and save lives.

New technology continues to allow more complex record breaking wells to be drilled. A greater challenge has placed onto API/ISO to increase their support, so API has created sub-committee resource groups to focus on today’s material. These resource groups search for the best steel chemistries and strengths for specific tubular performance properties. Three recent failures had a total cost of ten million dollars and in all cases were preventable.
Nondestructive Testing

API/ISO international standards are recognized as the leading requirements and recommendations for testing and field inspection of OCTG covering the practices and technology commonly used. For the various inspection methods these standards cover qualifications of inspection personnel, description of inspection methods, equipment calibrations, procedures and standardization. When these specifications are followed defects are found, disposition, indentified as acceptable or rejectable with tractability and painted.

NDT quality programs require full documentation including written procedures for all inspections to be performed. In most cases critical projects require quality programs to be certified by an independent agency to API Q1/ISO 29001 or ISO 9000 with complete documentation, including procedures for the calibration and verification of the accuracy of all measuring, testing and inspection equipment and materials. API requires constant verifications of equipment every four months.

Unit capability test are required and are to include records that verify inspection systems are capable of detecting the required reference indicators. System capability test document standardization of each different type of equipment; written procedures on assuring coverage, minimum signal from notch and the maximum signal to noise ratio, minimum of 100 % surface coverage. After each inspection is performed documentation for traceability is required to identify all system settings at the time of the inspection and a continuous chart recording, traceability of equipment calibration, system standardization, list written setup procedures used and a map or sketch of the test standard or pipe. Also complete documentation of each inspector including their education, training and qualification of performing inspections.

To prevent failures in the future we must remember how they happened in the past, by recording each step from the verification of material to be inspected, to the inspections to be performed, equipment to be used, how equipment is setup, material markings for example the pipe diameter, weight per foot, material grade, who manufactured it and what process used seamless or welded for manufacturing. Individual identification of each pipe or component by number is uniquely painted on the surface. The inspection sequence number is placed on the outside surface where it can be easily seen, always near the coupling end or box end of the pipe. It is very important to know the sequence of each piece and what inspection was performed in case a quality issue or failure occurs, all variables can be eliminated to determine root cause.

Visual Testing

Visual inspections are basic, but are most important since the technique is used in all other inspections performed. Dimensional inspections fall under the VT inspection section with the use of equipment to measure size and length. Full Length drifting verifies the internal diameter of the tube body full length meets the specified value by passing a drift mandrel inside the pipe, the drift is inspected and measured with a micrometer, then documented before use. Each drift inspection is recorded in a log book with the date, measured dimension and person who performed it. Measuring devices such as steel rules, steel length or diameter tapes are used to record length and diameter of the pipe. To measure depth of flaws on the surface a dial indicator gauge is used with an accuracy of .001”, each of these gauges are uniquely identified with a permanent serial number, certified traceable to NIST (National Institute of Standards and Technology) and verified every four months by a certified technician.

Visual testing prevents damaged pipes from being placed into service that may cause a failure, poor quality cost time and can be prevented. Good inspectors will identify defects such as mashed ends, damaged threads, wrong grades, incorrect diameter or wall thickness have all been root causes for pipe failure while in service. It is rarely realized when a string of pipe is placed in the well only the top pipe is holding all the weight below its threaded connection. A casing string 10,000 feet long weighing 26.00 #/ft has a total weight of 260,000 pounds just hanging. It is extremely important for connection inspections to be performed by qualified inspectors who know the long list of defects that have caused failure such as broken threads, cuts, grinds, seams, non-full-crested threads (including black-crested threads), laps, pits, dents, tool marks, fins, dings, burrs, torn threads (tears), handling damage, thick threads, narrow threads (shaved threads), galls, improper thread height, wicker (or whisker), cracks, chattered threads, wavy or drunken threads, improper thread form, arc burns, threads not extending to the centre of the coupling and other than those listed above, that break the continuity of the thread.
Magnetic Particle Inspection (MPI)

This inspection method aids visual testing to reveal surface breaking defects that have no visual characteristics and would not have been found otherwise. Magnetism must be present at time of inspection, MPI can only be performed on ferromagnetic material with clean surfaces. Once a sufficient field is applied iron fillings are spread over the surface to outline any breaks or areas of magnetic flux leakage. The inspection technique is the foundation for supplementing areas not covered by full tube body automation systems and is referred to as a Special End Area (SEA) inspection. It principally detects transverse and longitudinal flaws on the inside and outside surfaces including pins, couplings, exposed threads, upsets and integral connections for a minimum surface distance of 18 inches from the pipe face on both ends.

For detection of longitudinal orientated flaws, a circumferential magnetic field is induced in the pipe typically by inserting an insulated conductor inside the full length of the pipe, completing the circuit to the power supply and energizing the current to the appropriate value as per specification. The power supply includes an ammeter for indicating the applied current and is required to be audible or visible to indicate inadequate current. The conductor is insulated from the pipe surface to prevent electrical contact or arcing. For detection of transverse orientated defects, a longitudinal magnetic field is induced by a coil placed around the pipe end and applying current to the appropriate value as per specification. The number of turns in the coil shall is clearly marked so amper-turns can be calculated.

For localized inspections, a magnetizing tool call AC or DC Yoke is used, it’s a hand-held magnetizing device able to detect imperfections in any orientation on the surface between the poles when energized. The Yoke is a very valuable tool when verifying the exact location of a surface breaking defect in hard to reach areas.

Full-length magnetic particle inspections (FLMPI) are used for pipes with a larger OD (outside diameter) greater than the automated system’s capability, usually above the 13” to 16” OD range. This inspection is optional for the full tube body surfaces when automated systems are not available, used for casing, tubing, pup joints and plain-end drill pipe including upsets and attached couplings for longitudinal defects by applying magnetic particles on magnetized surfaces.

For all MPI testing field indicators are used to verify magnetism strength and orientation prior to performing inspection. API/ISO identify acceptable field indicators as slotted shims, strips and pie field indicators able to hold magnetic particles in field strength of approximately 5 Gs (gauss) when positioned on the outside surface with the artificial imperfection aligned in the appropriate direction. Magnetic particles are applied either dry or wet (in a suspension). Dry magnetic particles are to have contrast with the pipe surface and meet the referred to standard of ASTM (American Society of Testing and Materials). Wet magnetic particles are typically fluorescent particles suspended in a solution with low viscosity; non-fluorescent wet particles are also available. The advantage of wet fluorescent particles is the consistent and even coverage or flow over the pipe surface and it has a slightly higher sensitivity with its smaller grain size. A possible disadvantage of wet particles is they require a recirculation system, spray container or other means to be distributed particles, also fluorescent particles require an illuminate light to excite the particles referred to as a “Black Light”. The particle solution concentrate and light intensity are periodically verified and recorded by the inspector.

Electro-Magnetic Inspection (EMI)

This inspection method uses flux-leakage equipment in a system that produces a strong magnetic field to a region of the pipe where electronic sensors are scanning. The sensors detect magnetic flux fields that leak from defects in multiple orientations mainly focus in the longitudinal and transverse directions with the ability to find volumetric imperfections (sub-surface). Included in an EMI system is additional inspection methods to measure wall thickness, wall eccentricity and to compare pipe grades. Typically, these systems incorporate these four inspection stages in one single pass unit that can be field-portable as well as permanently mounted in a weather protected facility.

As part of the quality program all ammeters recording devices are calibrated and verified every four months additional unit standardization checks are perform periodically during the pipe inspection, at the beginning of each inspection shift, every 4 hours of continuous operation, every 50 lengths inspected, if unit power had an interruption, prior to equipment shutdown, prior to resuming operation after any repair or change to a system component that would affect its performance. If an unacceptable check of the system occurs all pipe shall be re-inspected back to the most recent acceptable system check. A system check refers to the unit’s ability to repeat consistent detection of
specify reference indicators at production speeds, typically machined notches to a maximum length, width and depth per specification. For example a critical inspection requires the length to be 2” maximum, width to be .040” maximum and depth to be 5% of specified pipe thickness (.027” depth for .545” wall thickness)

This inspection method detects pits, seams, laps, cuts and other imperfections rejectable if they penetrate the pipe wall. For critical products all imperfections greater than the 5% target reference must be detected and removed typically by grinding to eliminate stress risers that may cause failure or catastrophic lost.

**Ultrasonic Testing (UT)**

This inspection method uses sound waves that penetrant the wall thickness form the outside surface traveling to the inside surface investigating for flaws in the region of pipe where ultrasonic probes are scanning. The probes detect breaks in the material from defects in multiple orientations mainly focus in the longitudinal and transverse directions with the ability to measure flaws and wall thicknesses very accurately. Typically ultrasonic systems have probes position in a multitude of directions for a complete inspection as the pipe passes through unit. Most systems used for critical inspections are permanently mounted in a weather protected facility and can perform inspection of the pipe body for longitudinal and transverse imperfections (optionally oblique imperfections) using shave wave technique, wall thicknesses (minimum, average, maximum) using compression wave technique.

Ultrasonic has become the most advantageous tool in the past 20 years for full tube body inspections as well as localized inspections. A compression wave digital gauge is very portable and is widely used to verify actual wall thicknesses when UT unit’s defines low wall areas, for measuring remaining wall thickness after an imperfection has been repaired or removed by grinding and also to determine sub-surface flaw size or flaw area. The shear wave instrument is also a great tool that’s portable and hand-held able to detect and size imperfections in any orientation from the outside surface. Other uses include but not limited to inspection of the longitudinal weld seams produced by welding process.

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NDT is extremely important to the oil and gas industry it provides the most economical and greatest way to know if the manufacturing process and procedures used during production of new pipes were correct and that the product meets the well design and industry specification without changing, harming or structurally affecting the pipe inspected. Quality Control departments highly depend on the use of NDT to measure pipe wall thickness, to search for defects and to size defects that are below the surface and in hard to reach areas like on the internal pipe surface. NDT inspections systems provide high speed coverage for sensitive flaws enabling hundreds of pipe to be processed at high quality levels. For critical projects a combination of methods are employed such as EMI, UT and MPI to better target 5% deep flaws on all surfaces in addition to the threaded areas.

Today’s well engineers are requiring new drilling techniques as mentioned earlier to reach the higher more critical pay zones in extended reach areas. There is a constant pressure on today’s oilfield industry to meet aggressive goals with almost unlimited capital funding (hundreds of millions of dollar projects).

More well operators and drilling contractors are realizing the old tradition of accepting new pipe as not having defects has changed. They are more educated to the specification minimum requirements and are always searching for high quality pipe manufactures that will perform NDT above the specification before placing their string into service. As per API/ISO Table E.62 in Specification 5CT for new casing and tubing, little to no non-destructive test methods are required by the manufacture to API/ISO monogram Grades H-40, J-55, K-55, N-80 type1. All must receive a visual inspection and are not required to have their wall thickness determined, or checked by UT, EMI or MPI methods. Since these Grades are normally used in less critical environments the thinking is flaws that are present in the pipe will not propagate to failure.
Unfortunately, new technologies like directional and horizontal drilling are using OCTG in a way that was not known when the specifications were first written. It’s a buyer’s beware world and managers of Material Quality Programs should consider if Post Mill Inspections are required to know the quality of the material purchased and used. Most good quality pipe manufacturers will perform in house QC inspections to know their product does meet and exceed the specification. Because their was a shortage or long lead time to purchased and receive OCTGs many facilities became licensed by API/ISO and began flooding the market with Grades of H-40, J-55, K-55, N-80 type1 with no QC inspections leaving well operators horrible failures and in some cases 80 pipes dropped in the hole from threads parting and failing maintain toughness to hold the lower part of the string while tripping activities’ were performed. Failure cost began to rise when the crew was put on hold; while a fishing (pipe retrieval) crew was summoned, adding the delay in production tens of thousands of dollars of unnecessary cost are being wasted each day. If the pipe in not retrievable, the well will require a sidetrack or be abandoned. The risk management program should consider these type of situations where the cost of inspection is merely thousands of dollars with the knowledge of action was taken to minimize risk.

**Conclusion**

Post Mill Inspections detect defective new pipes every day, when a look is taken at what defects are found in new pipes that prevent failures the list is long. After reviewing previous inspection reports for over 650,000 pipes most were found rejectable for Damaged Connections (Threaded area) 57%, Laps 14%, Thin Wall 11%, Internal Surface Flaws 6%, Gouges 4%, No Drifts 3%, Pitting 2%, Mill Grinds 2%, Mid-Wall Inclusions < 1%.

In today’s competitive market reducing failure is the focus. NDT methods are the quality assurance tool being used to provide the snapshot in a time for present quality level of Casing, Tubing and Drill Pipe as it goes from being manufactured to finding its place into the wellbore.
New Drilling Rigs employ pipe handling equipment that also contributes to pipe damaged.

Damaged connections and damaged seals causes failures

EMI and Ultrasonic tube body inspection detect defects

Ultrasonic Shear Wave Detects Cracks