How NDT Methods Prevent Civil Structure Disasters

A Historical Analysis of the Glacial Rate of NDT Tech Adoption

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ABOUT THE AUTHOR

Jeffrey S. Monks consults on strategy with Metal Fatigue Solutions, a company that develops devices and systems that indicate the true status of fatigue damage in a metal component. It produces and markets the patented, Electrochemical Fatigue Sensor (“EFS”™), an instrument that detects microscopic growing fatigue cracks in metals. MFS’ technology is applicable to bridges and aerospace, as well as oil rigs, ships, cranes, railways, power plants, nuclear facilities, piping systems and others.

MFS is marketing its EFS and its other advanced crack-detection technologies to bridge asset managers, railroad companies and governmental agencies worldwide. It owns the only non-destructive testing (“NDT”) technology able to find growing cracks as minute as 0.01 inches – critical information that allows structural engineers to isolate and repair the more than 100,000 steel bridges in the US which have been classified as structurally deficient or functionally obsolete by the Federal Highway Administration. MFS holds an intellectual property portfolio with exclusive rights to seven patents.

Prior to MFS, Mr. Monks was the Sales and Marketing director of Lynchburg, VA-based Innerspec Technologies. Previously he served in the same role at DeW Systems of Hereford, England.

Earlier, Mr. Monks owned and managed his own NDT equipment and service companies and has been an active participant, leader and mentor to many in the NDT industry. He has been an active member of professional trade organizations since 1988 with a high emphasis of participation in, and recognition by, the American Society for Nondestructive Testing.

EXECUTIVE SUMMARY

Industry has seen many cases of history repeating itself -- in particular the glacial rate of adoption of advanced NDT technologies. These new NDT technologies were resisted by the industries that stood to gain the greatest benefit despite clear, measurable and extensive experience or data.

Initially commercialized in 2005, Electrochemical Fatigue Sensor ("EFS") appears to be the world's only, truly definitive metal fatigue assessment technology. Until EFS, little progress had been made in gauging crack growth and the extent of this insidious strength-sapping phenomenon.

EFS is able to find growing cracks as minute as 0.01 inches – critical information that allows structural engineers to isolate and repair the more than 100,000 US steel bridges classified as structurally deficient or functionally obsolete by the FHWA. Available and proven since 2005, EFS is slowed by the same inertia and ~~,~~ resistance to change that sacrifices performance and safety for status quo.

- In 1865, the steamboat Sultana blew up on the Mississippi River killing 1,500, caused by boilers exploding. In 1905, a shoe factory boiler in Brockton, MA exploded killing 58 and injuring 117. Boiler safety became a higher priority and drove development of the ASME Boiler Code.

- In 1936, speeds at the Indianapolis Motor Speedway were exceeding 125 miles per hour for the first time, with many accidents with serious injuries and fatalities. The Speedway began to inspect with NDT, primarily Magnetic Particle Inspection of critical steering components.[2] Despite the availability of superior NDT technology, regulated inspection requirements was launched only after serious injuries and deaths.

- In the 1940s, eight allied Liberty Ships were lost due to a condition known as Brittle Fracture in welds. These tragic losses drove additional testing methods based on the ASME Pressure Boiler Code from 1915 – written nearly 30 years earlier! Magnetic particle inspection and Radiography were accepted methods for Boiler inspection in the 1931 Revised Boiler Code, but not required for ship building. The result was that a certain percentage of welds are inspected for flaws (up to 100% on critical applications). Developed in reaction to (avoidable) tragedies, weld inspection is the standard.

- Prior to Three Mile Island, long before Chernobyl and Fukushima nuclear disasters, in his 1974 Resignation Letter a Scientist with Aerojet Nuclear Co. wrote: *"The AEC is using shaky and unproven computer predictions as a basis for answering such vital questions as the effectiveness of reactor safety systems in preventing catastrophic accidents. This is wholly unacceptable.*

  Several nuclear disasters later, the nuclear industry's methods of inspection adhere to the Confidence Philosophy, risk-based inspection and set the standard for safety and reliability.

- In the 2000's decade a revolutionary technology, ultrasonic EMAT, was developed. It enables ultrasonic inspection without the need for couplant. Yet even conventional ultrasonic methods have struggled in industry implementation for more than a decade.

Nine years after the initial commercialization of EFS, the U.S. bridge and infrastructure industry maintains inspection procedures that are obsolete and unreliable. Will the public and private infrastructure industries break the cycle of inertia-disaster-'epiphany'-solution?

Or will the civil infrastructure industry require a major structure failure to realize the risk they sought to avoid was inherent in their decisions to avoid evaluating and adopting state of the art technologies? How many major bridge collapses will it take, how many innocent lives lost, to convene the Congressional subcommittees grilling industry officials to ask why they were still using NDT technology from the 1990s?

FORWARD

As an NDT professional for 27 years, I have observed many cases of history repeating itself in industries -- in particular the glacial rate of adoption of advanced NDT technologies. Surprisingly, these new NDT technologies were resisted by the industries that stood to gain the greatest benefit from them despite clear, measurable and extensive experience or data.

Winston Churchill famously stated, *"Those who fail to learn from history are doomed to repeat it."*

Throughout the 20th century, weld inspection was resented for decades by welders until the industry was able to convince the welding profession that an "X-Ray Welder" provided a higher value position than an ordinary welder with many years of experience. X-ray welders today are proud of this title.

In the early 1990s, computing power and computer-based innovative instrumentation began to be introduced. NDT industry specifications and procedures were based only on legacy inspection methods and industry was reluctant to accept new PC-based instruments and systems. In cases where computerized inspection was developed, there were no standards; neither codes nor personnel certification and qualification processes were recognized. Ultimately the inspection industry has evolved with computer-based methods the norm, but this was achieved only after many years of opportunity cost in improved inspection, ROI, efficiency and productivity.

By the mid 1990's, RD Tech was revolutionizing the NDT industry, primarily through weld inspection with a new visualization system using ultrasonic methods called ~~Phase~~Phased Array. Unfortunately, the industry adoption of this technology took so long that it lost many years and tens of millions of dollars of industry cost savings and state of the art data.

~~Phase~~Phased Array eventually became the industry standard only after a decade of struggle to change codes, specifications, requirements and accepted practices. Training of personnel on this new technology became the stumbling block for wider acceptance. RD Tech became quite proactive and provided training to inspectors throughout the extended ~~Phase~~Phased Array introduction period.

In the 2000's decade a revolutionary technology, ultrasonic EMAT, was developed first within Babcock and Willcox Company and later by Innerspec Technologies. Ultrasonic EMAT methods allow for ultrasonic inspection without the need for couplant. In EMAT Inspection, the sound is generated by induction (magnetostriction, Lorenz forces) not transduced from a sensor on the surface. Eliminating couplant for ultrasonic inspection and the ease of generating effective guided waves (nearly impossible with piezoelectric methods) provided, for the first time, the capability to perform many desired inspections such as very high temperature inspection and full volumetric weld inspection.

EMAT still struggles for acceptance in industries where codes do not adequately identify the method despite its compelling advantages. Even conventional ultrasonic methods have struggled in industry implementation for more than a decade especially in computerized systems.

We are seeing history again repeat itself in the bridge and infrastructure industry through its slow adoption of next-generation, scientifically and economically proven technologies that revolutionize the industry through measurable results and upgraded safety. Nine years after the initial commercialization of EFS NDT technology, the U.S. bridge and infrastructure industry maintains inspection procedures that are obsolete and unreliable.

Ironically, the need for EFS technology today has never been greater. Capital is scarce and political forces at the federal, state and municipal level have not adequately funded the nation's bridges and infrastructure despite its desperate condition.

Today, we see the vitally important infrastructure industry being forced to attempt to maintain these structures far longer than their design life, with minimal funding. The methods implemented must maximize the results obtained to enable smart, high ROI decisions of how to prioritize expenditures, investments, retrofits, repairs and replacements. With the availability of a superior technology (EFS) capable of accurately determining the actual condition of these structures far in advance of conventional inspection methods, safety can again be paramount.

Let's review the historical record to see if the lessons learned might prevent another case of industry inertia slowing the implementation of valuable and data rich methods to improve the nation's infrastructure.

INTRODUCTION

Throughout history disasters and high profile failures have driven new regulations, codes and/or new processes to minimize the future risk due to such failures. Nondestructive testing methods are commonly included in such reactions to disasters and its promotable public safety assurances. Tragically, radiography, ultrasonic inspection and other NDT methods have undergone repeated resurrections as critical inspection solutions only in reaction to disasters.

In the transportation industry, inspection methods for structures such as highway bridges, railroad bridges, cantilever signage, etc. has not changed a great deal since the late 1900s. All these methods suffer one important shortcoming: they do not predict fatigue and carry an alarmingly low probability of detection (POD) rate. While fatigue cracks occur over time at microscopic levels, visual inspection methods lack an early warning of fatigue issues. Bridge designers over-engineer and over-build structures to ensure integrity but, since the 1960's, have been forced to continually reduce redundancy without an increase in effective inspection.

While somewhat effective, conventional methods are not capable of determining the status of fatigue cracks. This means determining whether cracks are growing (greater risk) or not actively growing (limited risk). Other methods that have been used to "estimate" that information either rely on assumptions (reducing their accuracy to the accuracy of those assumptions) or depend on signal to noise ratio that is not conducive to accuracy.

When discussing NDT in any industry, it is critical that the test method and inspection procedure implemented are absolutely correct to ensure that structural defects or anomalies are detected.

"The Confidence Philosophy" states that after subjecting a component to a nondestructive test, if no indications are found, one of two assumptions can be made:

1. There are no deleterious defects in the component, or

2. Defects exist, but the proper test procedure or method was not implemented.

The Confidence Philosophy requires all industries thoughtfully examine their current methods, and any other methods, to ensure that the inspection results provide the highest degree of confidence.

HISTORICAL CASE STUDIES

Case Study - Weld Inspection History

In 1865, the steamboat Sultana blew up on the Mississippi River killing 1,500. The catastrophe was caused by boilers of the steamboat exploding. In 1905, a boiler in a shoe factory in Brockton, MA exploded killing 58 and injuring 117. Boiler safety became a higher priority as a result of these failures and drove development of the ASME Boiler Code to improve the safety of boilers and ultimately other pressure vessels.

Fast forward 75 years later, during WW II, the shipbuilding industry experienced explosive growth to fill war-time ship requirements. Welding was replacing riveting as a method of joining metals in the ship building industry. The use of welding, especially sub arc welding, allowed the industry to build ships with much greater efficiency than previous methods. Along with this new joining technology came new challenges, mainly ensuring the welds applied were of adequate quality. A single failure of a critical weld could cause a tragedy at sea.

During this period, eight Liberty Ships were lost due to a condition known as Brittle Fracture. These losses were tragic and became the impetus to implement additional testing methods based on the ASME Pressure Boiler Code from 1915 -- nearly 30 years earlier. In its infancy, the Boiler Code specified testing comprised of an inspector with a hammer tapping the structure and listening to the tone of the sound generated in the metal. A dead, empty sound would indicate a weld defect.

While this was the only method used for this application at the time, there in fact existed superior methods of inspection. Magnetic particle inspection and Radiography were accepted methods for Boiler inspection in the 1931 Revised Boiler Code, but were not required for the ship building industry. Additionally, liquid penetrant and ultrasonic inspection methods were young but proven techniques for inspection of materials and weldments.

The result is that a certain percentage of welds are inspected for flaws (up to 100% on critical applications). Today, weld inspection and welder qualification are standard requirements in nearly all industries. Originally developed in reaction to (avoidable) tragedies, weld inspection is the standard to prevent further tragedies.

Case Study - Auto Racing

In 1936, speeds at the Indianapolis Motor Speedway were exceeding 125 miles per hour for the first time. These speeds were considered dangerously fast and many accidents with serious injuries and fatalities occurred. To make auto racing safer, the Speedway's Board launched a study to determine root cause of accidents. Several potential causes of these accidents were identified and, as a result, the Indianapolis 500 began to inspect with nondestructive methods, primarily Magnetic Particle Inspection of critical steering components.[2]

After studying Magnetic Particle inspection methods in 1936, the speedway began to mandate all steering components, arms, etc. be inspected. Over the years, additional components were added to the list of inspection required components. As this inspection requirement was making racing measurably safer, the methods used were also expanded. Today, testing is provided by qualified nondestructive testing personnel who volunteer their time to ensure the highest level of safety for drivers, teams and fans.

Adding to magnetic particle methods, liquid penetrant, ultrasonic, eddy current, and x-ray are used. Recently the “MAUS, Ultrasonic C-Scan system” began inspecting composite components for impact damage detection and disband inspections.

While the auto racing industry is a safe sport, especially when the remarkable speeds are considered, the implementation of regulated inspection requirements was launched only after many serious injuries and fatalities despite the availability of superior NDT technology.

Case Study - Nuclear Power Industry
The International Atomic Energy Association’s (IAEA) states that NDT is necessary for safety and reliability in the nuclear power industry. In the earliest decades of nuclear power generation, the AEC was not initially as dedicated to such importance on safety and reliability as it might have been:

“A synopsis of this chronology might suggest that the first ten years of nuclear power development were devoted to demonstrating that power reactors could be designed, built, and operated; the second ten years were devoted to showing that power reactors might be operated economically; the third decade saw the rise of a viable commercial industry, the fourth decade, punctuated by the accident at Three Mile Island, was a mix of rapid commercial growth coupled with increasing government regulation, the fifth decade, despite the Chernobyl accident, was highlighted by serious public skepticism and a reaffirmation by the nuclear industry to provide a safe source of electrical generation. The nuclear industry is now well into the sixth decade of nuclear power, public skepticism is still a major factor guiding the future of nuclear power both in the United States and internationally.1

Prior to the incident at Three Mile Island and long before the Chernobyl (Ukraine) and the Fukushima (Japan) nuclear disasters, in his 1974 Resignation Letter Carl J. Hocevar, an Associate Scientist with Aerojet Nuclear Company, wrote the current procedures of predicting nuclear factor defect or failure are inadequate to assure safety and reliability:

“While analytical models for predicting the fluid behavior during a LOCA have been developed by both the nuclear industry and the AEC, the techniques in general are not capable of describing actual physical situations with a reasonable degree of reliability. The AEC is using shaky and unproven computer predictions as a basis for answering such vital questions as the effectiveness of reactor safety systems in preventing catastrophic accidents. This is wholly unacceptable.

Since that time, the nuclear industry’s methods of inspection adhere to the Confidence Philosophy and the level of its risk-based inspection has become the benchmark any industry strives to replicate whenever safety and reliability are the primary goals.

RISK-BASED INSPECTION

“Risk-based inspection (RBI) is a methodology that, as opposed to condition-based inspection, involves quantitative assessment of the probability of failure (PoF) and the consequence of failure (CoF) associated with each equipment item, piping circuits included, in a particular process unit. A properly-implemented RBI program categorizes individual pieces of equipment by their risks and prioritizes inspection efforts based on this categorization.

RBI is used to identify and understand risk drivers to prioritize inspection-related activities, usually by means of nondestructive examination (NDE) to reduce the uncertainties around the true damage state of the equipment and the dynamics leading to such. The resulting inspection plan outlines the type and scheduling of inspection for an asset. In addition to NDE, additional risk mitigation activities identified by a

RBI assessment might include a change in material of construction, installation of corrosion resistant liners, operating condition changes, injection of corrosion inhibition chemicals, etc.”

Along with Structural Reliability/Risk Analyses (SRRA), the nuclear industry has set a high standard of Risk-Based Inspection and asset management. These implementations from the nuclear industry are already finding their place into code bodies such as ASME and other industries including the US highway system although still in its infancy today. MAP 21 program initiatives had set goals for better asset management and RBI, but will lose funding absent a new highway funding bill in 2015.

Bridge owners, Departments of Transportation and the Federal Highway Administration must optimize the use of their limited funding, via quantitative technologies, providing data rich results, which can provide the highest ROI, and best platform for intelligent decisions, to improve asset management and life span improvement of the existing infrastructure.

90% FAILURE RATE -- STATE OF THE BRIDGE INSPECTION INDUSTRY

A 2001 study conducted at the FHWA NDE Validation Center revealed that bridge inspectors correctly identified crack indications at fatigue sensitive locations less than 10% of the time. That is, 90% of fatigue cracks are missed by conventional inspection methods. When one considers that Visual Inspection, often from a vehicle, is the normal method to detect the presence of fatigue cracking it is quite easy to comprehend such a low Probability of Detection.

Accordingly, repairs to structures were being made 80% of the time in areas which did not require repair. The study concluded that visual inspections are ineffective and waste valuable resources when it comes to fatigue cracking. Given the annual growth of vehicular traffic utilizing this infrastructure, the need for a better management system of these assets has never been greater.

THE ELECTROCHEMICAL FATIGUE SENSOR (EFS) SYSTEM

EFS Offers Bridge Owners a Wide Range of Advantages Including:

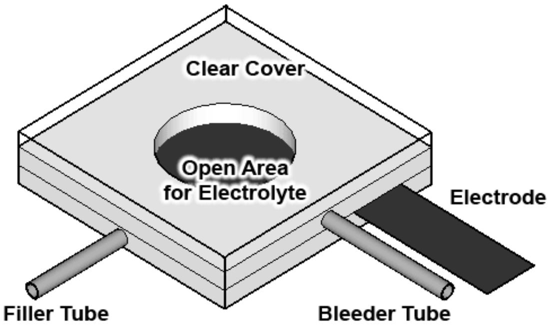
- Knowing the status, growing or not growing, of the fatigue crack immediately
- Knowing the status of similar details
- Prioritizing repairs
- Repairing only what is necessary
- Verifying the effectiveness of the repairs/retrofits immediately
- Determining the most cost effective retrofit method prior to widespread installation.

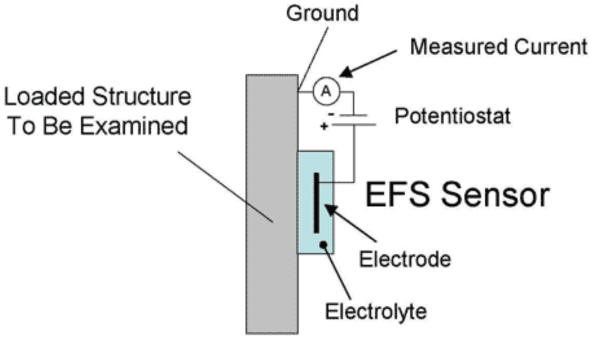
This dynamic testing method is more sensitive, accurate, and cost effective than all other methods at determining whether a fatigue crack is growing.

The Electrochemical Fatigue Sensor (EFS) is a non-destructive crack inspection and monitoring technology that determines if a growing crack exists at an inspection location. It can be used on existing cracks to determine their activity under ambient loading, or at similar fatigue susceptible details to determine the existence of growing cracks that can be missed by conventional inspection methods. The EFS can also immediately determine if repairs and retrofits are effective by being able to detect precursors to crack initiation and propagation.

Similar in concept to a medical EKG, EFS is used to determine if actively growing fatigue cracks are present. An EFS sensor is first applied to the fatigue sensitive location on the bridge or metal structure, and then is injected with an electrolyte, at which point a small constant voltage is applied.

The system subsequently monitors changes in the current response that results from the exposure of fresh steel during crack propagation. The EFS system consists of an electrolyte, a sensor array (one reference and one crack measurement sensor) and potentiostat for applying a constant polarizing voltage between the bridge and sensor, as well as data collection and analysis software.





The current response from the sensor array indicates quickly and clearly, whether a growing crack exists at the inspection location. Data is presented in both the time domain and the frequency domain. An algorithm, specifically written for this system, automatically indicates the level of fatigue crack activity at the inspection location

CONCLUSION

Initially commercialized in 2005, EFS appears to be the world’s only, truly definitive metal fatigue assessment technology. Until EFS, little progress had been made in gauging crack growth and the extent of this insidious and largely invisible strength-sapping phenomenon.

With EFS it is now possible to conduct the appraisal of steel structural members using a technique which does not require any knowledge of past structural or loading history for the object to be monitored. This provides an answer to the metal fatigue problems of a broad array of industries such as bridges and aerospace, ships, cranes, power plants, nuclear facilities, chemical plants, mining equipment, metal windmills and “heavy iron.”

Electrochemical Fatigue Sensor inspection technology is available and proven, but slowed by the same forces of inertia, resistance to change and “conservative decision-making” processes that sacrifice performance and safety for familiarity and status quo. The EFS is greatly under-utilized.

How many major bridge collapses will it take, how many innocent lives lost, to convene the Congressional subcommittees grilling industry officials to ask why they were still using NDT technology from the 1990s?

Will the civil infrastructure industry require a major structure failure to realize the risk they sought to avoid was actually inherent in their passive daily decisions to avoid evaluating and adopting state of the art technologies?

Similar to radiography and ultrasonic inspection methods in the mid 1900’s in boilers and shipbuilding, and much like Magnetic Particle inspection, liquid penetrant inspection and radiography in the racing industry up to the late 1970’s – will the public and private infrastructure industries break the cycle of inertia-disaster-‘epiphany’-solution?

Much like the NDT methods introduced and refined in the nuclear industry starting in the 1950's, EFS is providing tremendous benefits to public safety, structural reliability and a superior ROI beyond any existing standardized method of inspection. The Infrastructure industry can generate a lucrative payback by implementing technologies offering a baseline inspection of some percentage of all at-risk structures, initially, to understand their true condition.

Proactive inspection methods must be implemented now, not in reaction to disaster. Implementation of EFS inspections now is the most responsible action to establish correct protocols, develop procedures and draft the codes for its use, all while gaining valuable data.

This is the best means to implement a confidence-based approach to standards development and assure public confidence in its civic structures.

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