



Aging Power, Informed Decisions

How advanced and emerging NDT technologies are transforming decisions

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A Heartful Thank's to all the Contributors

**Business &
Communications**
Editor in Chief
Santosh Gavankar

Business Head
Govind Walavalkar

Marketing
Marketing Director
Ravindra Warang

Marketing Head/Editor
Kadambari Bendre

Marketing Specialist
Prathmesh Kamat
Himanshu Mishra
Rushil Gupta

Copy
Copy Writing
Abhishek Sawant

Design
Creative Lead
Pratik Satpute

Design Lead
Bhavesht Sawnat

Graphics
Komal Vishe
Priyanka Patra
Mrunmai Patil

Technical Content
Abhishek Chaurasia

Special Thanks to our Contributors

Jefy Jean Anuja Gladis
Anmol Biring
Gonçalo Sorger
Iikka Virkkunen
Christer Söderholm

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Editorial

Aging Assets Still Running

Power generation has never been a low-stakes business. But today, the margin for error is thinner than ever.

Across fossil and nuclear plants, many critical assets are older than they were ever designed to be. Steam turbines have seen decades of starts and stops. Pressure vessels have lived through heat, stress, and corrosion. Nuclear components operate where “close enough” is never good enough.

Keeping all of this running safely depends on what’s happening inside the material long before anything shows up on the outside.

That’s where non-destructive testing earns its keep.

Today, NDT in power plants is less about ticking boxes during outages and more about answering hard questions: Is this real? Is it changing? And what happens if we don’t act yet? Inspectors aren’t just reporting signals anymore; they’re helping decide whether an asset runs another cycle or reaches its limit. Ultrasonic data, eddy-current responses, and radiographic images now sit directly in reliability and life-extension decisions.

This February edition of NDT Trends looks at inspection as it actually happens inside fossil and nuclear plants where reliability is worked out flaw by flaw, decision by decision.

Because when the lights stay on, it’s rarely luck. It’s usually because the right signal was understood at the right time.

Santosh Gavankar
Editor-in-chief

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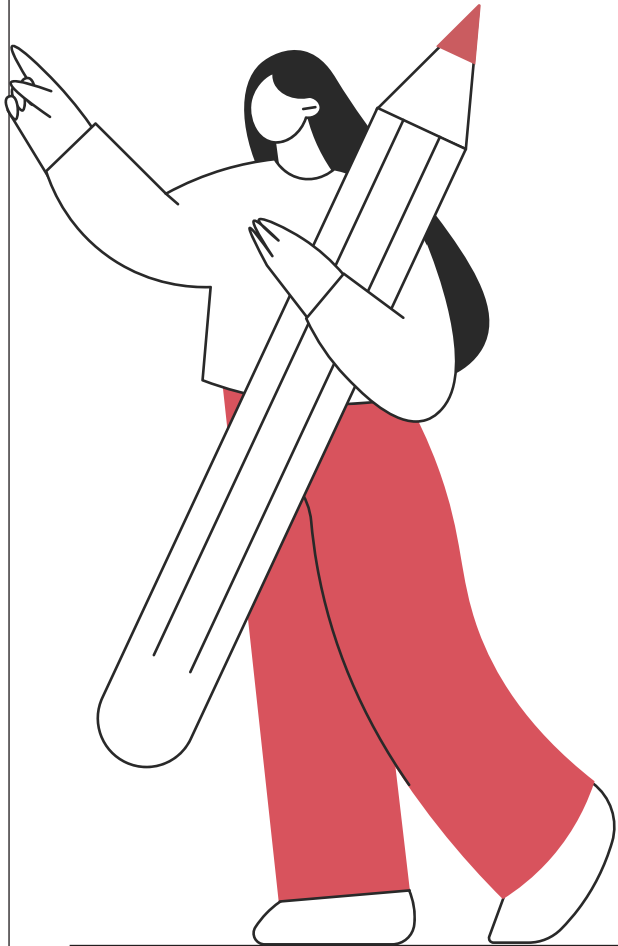
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Top Stories

Insights in Focus

*Top Stories Shaping
the NDT Industry*



ESAB Corporation to Acquire Eddyfi Technologies in \$1.45 Billion Deal



Image Source - @seeking_alpha

ESAB Corporation (NYSE: ESAB), a focused global industrial compounder, has announced that it has entered into a definitive agreement to acquire Eddyfi Technologies, a global leader in advanced inspection and monitoring technologies, for \$1.45 billion. The transaction is expected to create an unrivaled provider of end-to-end workflow solutions spanning fabrication, inspection, and monitoring.

Eddyfi is expected to generate approximately \$270 million in revenue and \$80 million in adjusted EBITDA in 2026, or \$100 million with expected annualized run-rate synergies. The acquisition will be funded through a combination of cash on hand, debt, and \$318 million of fully committed equity. The transaction is expected to close in mid-2026, subject to customary closing conditions and regulatory approvals.

As part of the agreement, ESAB has made firm commitments to maintain Eddyfi’s workforce and head office in Quebec City, reinforcing continuity and long-term investment in the business.

Commenting on the acquisition, Shyam P. Kambeyanda, President and Chief Executive Officer of ESAB Corporation, said: “This acquisition is a pivotal step that strengthens ESAB

and sets the course for our next phase of growth. We are thrilled to welcome Eddyfi into the ESAB family.”

He added: “With the addition of Eddyfi, ESAB becomes the unrivaled provider of a full workflow solution spanning fabrication, inspection and monitoring. This new complete offering will contribute to ESAB’s position in the industry as a partner of choice for our global customers, where quality, productivity and uptime are non-negotiable.”

According to Kambeyanda, the acquisition significantly expands ESAB’s growth potential. “This acquisition further expands ESAB’s total addressable market by approximately \$5 billion and accelerates our journey toward a portfolio that is faster growing, higher margin and less cyclical. The combination also strengthens our exposure to attractive, high-growth end markets including Aerospace and Defense, Nuclear, Energy and Civil Infrastructure.”

ESAB expects Eddyfi to deliver high-single-digit organic growth with gross margins exceeding 65%. “As we integrate the business and deploy the ESAB Business Excellence System (EBXai), we anticipate unlocking \$20 million of synergies and additional operational and commercial benefits. This acquisition is fully aligned with our disciplined capital allocation framework and our commitment to long-term shareholder value creation,” Kambeyanda concluded.

Martin Thériault, Chairman and Founder of Eddyfi Technologies, welcomed the announcement, saying: “Joining forces with ESAB marks an exciting new chapter for our team. ESAB brings the scale, resources and long-term commitment needed to support our people, strengthen our impact with customers and honour the legacy we have built. This is far from being the end of our story. It is the beginning of a new chapter defined by growth, pride and renewed momentum.”

The acquisition positions ESAB as a comprehensive solutions provider across critical industrial workflows, combining fabrication expertise with advanced inspection and monitoring technologies to serve high-value, safety-critical industries worldwide.

Voliro and Gresco UAS Announce Strategic Partnership for US Inspections



Image Source - @Voliro AG

Voliro, a global provider of advanced aerial robotics for industrial inspection, has announced a strategic partnership with Gresco UAS, a U.S.-based company specialising in professional drone and robotics inspection solutions. The collaboration brings Voliro’s next-generation aerial inspection technology to infrastructure and industrial asset owners across North America, strengthening safety, efficiency, and data quality in inspection operations.

As part of the partnership, Gresco will offer the Voliro T, a purpose-built aerial robotics platform designed for close-contact inspection and non-destructive testing (NDT) of complex infrastructure. The system’s omnidirectional flight and thrust-vectoring capabilities enable it to safely stabilise against structures and perform precise, repeatable contact-based inspections. This makes it particularly well-suited for challenging environments such as transmission towers, industrial facilities, and telecommunications infrastructure.

Combined with Gresco’s operational expertise, deployment support, and customer enablement capabilities, the collaboration delivers end-to-end inspection solutions that reduce the need for personnel to work in hazardous environments while providing high-quality inspection data to support informed asset condition assessments.

Commenting on the partnership, Allen Wheeler, Manager of Customer & Vendor Success at Gresco UAS, said: “At Gresco UAS, our job is to help critical-infrastructure teams work safer and smarter,” said Allen Wheeler, Manager of Customer & Vendor Success. “Partnering with Voliro expands the advanced aerial inspection capabilities available to our customers, with Gresco ensuring smooth deployment and ongoing support so teams can put the technology to work on day one. The outcome is straightforward: safer operations, higher-confidence data, and solutions that fit seamlessly into existing inspection workflows.”

Laurent Zimmerli, Vice President of Growth at Voliro, added: “Gresco’s expertise in autonomous robotics solutions delivery makes them an ideal partner. Together, we’re helping inspection teams adopt innovative unmanned systems that improve safety, reduce operational risk, and unlock new levels of inspection insight.”

The Voliro T is now available to customers across the United States through Gresco, supporting a wide range of industrial inspection applications where safety, data quality, and operational efficiency are critical. The partnership underscores the growing role of advanced aerial robotics in modern inspection workflows and reflects increasing industry adoption of unmanned systems for asset integrity management.

Energy Sector Greenfield Milestone: Aramco And CorrosionRADAR Set New Benchmark For Data-Led Asset Integrity Management



Image Source - @CorrosionRADAR

Aramco, the world’s largest energy company, is expanding its partnership with CorrosionRADAR, the global leader in Corrosion Under Insulation (CUI) Risk Monitoring Solutions, as it deploys the company’s predictive CUI monitoring solution at a major new greenfield project in Saudi Arabia.

The solution - which delivers continuous, remote detection and monitoring of Corrosion Under Insulation through data-led insights and AI-optimised software - is being installed at scale across the new facility, providing clear visibility of asset conditions from the very outset of the project.

Installing the solution at the design stage will provide significant benefits to Aramco, including improved CUI management planning, substantial cost savings, and extended asset lifetime.

Connected by CorrosionRADAR’s Clarity software, which uses predictive analytics models, machine learning and AI, to deliver insights for faster, more confident decision-making, a substantial number of assets will be monitored for localised corrosion and moisture ingress.

Showcasing the collaboration at the 19th Middle East Corrosion Conference and Exhibition (MECOC) in Saudi

Arabia, representatives of the Aramco Greenfield Project Management Team (PMT) highlighted how they are embedding CorrosionRADAR’s solution during the Front-End Engineering Design (FEED) stage of the project and implementing it at the site during the Engineering Procurement and Construction (EPC) stage. This is leading to smarter design choices, CAPEX savings in the shorter term and OPEX savings in the medium term, transforming Aramco’s approach to CUI management and setting a new benchmark for asset integrity.

A PMT representative said, “With Corrosion Under Insulation accounting for significant pipeline maintenance costs in some of our facilities, it poses a serious threat to the future success of this development. To address this, we are working closely with CorrosionRADAR to deploy its predictive CUI monitoring solution throughout the Greenfield project from Day One. This approach will ensure we achieve continuous CUI visibility, improved asset integrity, and, most importantly, greater operational efficiency1”

During his keynote opening speech at the 19th MECC, Ahmad O. Al-Khowaiter, Executive Vice President of Technology & Innovation at Aramco, highlighted the value CorrosionRADAR is already delivering across the company’s operations. He explained that with CUI being one of the most persistent and expensive challenges across all industries, billions of dollars in savings can be realised just by embedding AI and other corrosion control technologies into long-term asset strategies.

He said: “The technological revolution we are now living through is changing how every industry operates. The advent of AI and big data is taking us into a new world where opportunities are limitless, and we are moving at a pace none of us have experienced before. AI will give us the power to predict failures before they occur, optimise maintenance schedules and extend the productive life of critical assets.”

O. Al-Khowaiter also highlighted how solutions such as CorrosionRADAR’s predictive CUI monitoring solution are transforming how Aramco addresses these industry challenges, both now and in the future. He continued: “CorrosionRADAR’s technology is already delivering huge value through inspection cost reduction, improved uptime, and optimised turnaround planning.”

Dr. Chiraz Ennaceur, Chief Executive Officer and Co-Founder at CorrosionRADAR, said: “Our latest project with Aramco is an important example of how embedding a CUI monitoring solution across a facility from the outset, will have a transformative impact on long-term asset strategies

and maintaining asset health. By prioritising data, machine-learning and predictive strategies over reactive ones, Aramco will be able to detect early indicators of corrosion and take informed action against any damage – improving safety, reducing costs, and enhancing operational efficiency.

“We look forward to working alongside Aramco and the wider industry to continue to advance CUI management practices and help set new global standards for the future of asset integrity.”

CorrosionRADAR is the global solution provider for CUI risk monitoring, combining the power of data, product, and expertise for the highest quality prediction of when and where corrosion will occur. CorrosionRADAR’s solutions use data analytics software to monitor and predict risk remotely, allowing businesses to make data-driven decisions about their industrial assets, saving time and money, while enhancing safety and ensuring the longevity of critical infrastructure.

TMK Launches VR Simulator for NDT Training



Image Source - @Honeywell_Process_Solutions

The Pipe Metallurgical Company (TMK) has developed a virtual reality (VR) simulator designed to train and certify non-destructive testing (NDT) specialists in manual quality control of pipe products and coatings using the ultrasonic thickness testing method. The project has completed pilot testing at several TMK enterprises and is being implemented under the supervision of TMK2U Corporate University, TMK++ and the TMK Accelerator.

The VR simulator incorporates operational algorithms for six of the most commonly used ultrasonic thickness gauges deployed across TMK facilities. These non-destructive testing instruments are used to measure the wall thickness of finished pipe products. The simulator allows trainees to select specific inspection tools and test objects, offering a realistic and configurable NDT training environment.

The software platform supports three operating modes—training, testing and examination—enabling comprehensive skill development and competency assessment. Through the use of VR headsets, trainees are immersed in production-like conditions that closely replicate real manufacturing environments. This allows users to practice correct equipment configuration and identify areas of insufficient

wall thickness in pipes, bends and split tees using ultrasonic testing techniques.

A key innovation of the simulator is its voice-enabled measurement input, introduced for the first time in this type of NDT training equipment. This feature enhances realism and aligns closely with on-site inspection workflows. Designed as a universal training solution, the simulator is ready for replication across all TMK enterprises.

The simulator was developed by a multidisciplinary team comprising specialists from TMK's IT division (TMK++), TMK2U Corporate University, TMK's Scientific and Technical Center, the company's quality unit, and a partner company that graduated from TMK's corporate Accelerator. During development, the team created a standardized virtual production workshop, defined detailed technical specifications, and developed operational scenarios tailored to ultrasonic non-destructive testing.

"TMK is actively implementing digital and VR technologies in all areas of its business. The new simulator will reduce the preparation time for employees to work in real production, while maintaining the quality of training, effectively assessing their competencies and optimizing the certification process. Such solutions are especially important because the company employs young professionals who have grown up in a digital environment and are accustomed to interactive formats. We are developing training tools in such a way that they match their information perception model," said Elena Pozolotina, TMK's Deputy General Director for Personnel Management.

The newly launched platform marks the tenth simulator developed by TMK for workforce training. Similar simulation tools are already used within the company to train and validate professional skills in pipe rolling workshops. With the introduction of VR-based ultrasonic NDT training, TMK continues to advance digital transformation in quality assurance, strengthening inspection reliability and workforce readiness across its manufacturing operations.

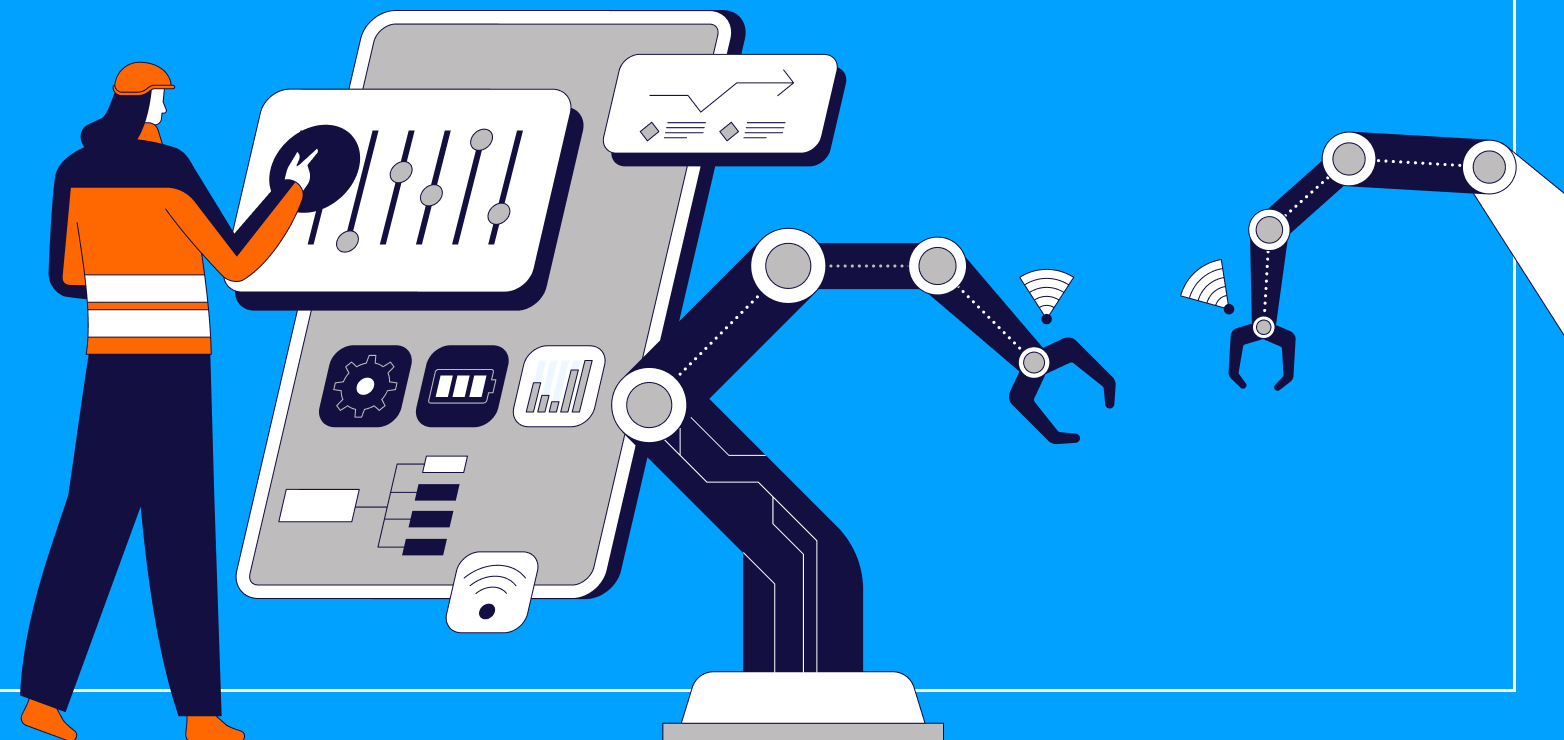


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How NDT Is Holding Together Aging Power Assets in a High-Risk, High-Demand Era

Power plants don't fail loudly until they do.

M

ost of the time, they give subtle warnings. A slight change in vibration. A barely noticeable wall-thickness loss. A faint ultrasonic response that doesn't quite look right, but doesn't scream danger either. In steam turbines spinning for decades, in pressure vessels holding enormous energy, and inside nuclear reactors where failure is simply not an option, these small signals are everything.

This is where non-destructive testing quietly earns its place not as a support function, but as the backbone of modern power generation.

For much of the world's power infrastructure, the story today is no longer about new builds. It's about assets that are older than the engineers currently responsible for them. Steam turbines commissioned in the 1970s. Boilers and pressure vessels operating far beyond their original design life. Nuclear reactors navigating license extensions under tighter regulatory scrutiny than ever before.

The question operators are asking is no longer “Is it working?” It’s “Can we trust it tomorrow?”

When Power Assets Age, Assumptions Expire

In fossil fuel plants coal and gas alike components live under relentless conditions. High temperatures. Cyclic stresses. Corrosive environments. Over time, fatigue, creep, and corrosion don’t announce themselves dramatically. They evolve quietly, often deep inside thick sections of metal.

Nuclear power plants face an even harsher reality. Reactor pressure vessels, internals, piping circuits, and steam generators operate under neutron irradiation, thermal gradients, and safety margins that leave no room for guesswork. Every inspection decision carries regulatory, operational, and public-confidence consequences.

Across both sectors, one truth is shared: failure is unacceptable, and surprises are unaffordable.

That’s why inspection has shifted from being a periodic activity to a strategic discipline. And NDT has moved from the background into the decision-making room.

From “Check and Move On” to “Understand and Predict”

There was a time when inspections were largely manual and scheduled. Ultrasonic checks during outages. Eddy-current testing during shutdowns. Radiography when access allowed. These methods did their job but they offered snapshots, not narratives.

Today’s reality is different.

Operators are no longer satisfied with knowing that a flaw exists. They want to know:

- How fast it’s growing
- Whether it actually threatens integrity
- If it can be monitored instead of repaired
- And how long the asset can safely remain in service

This shift has pushed NDT toward reliability-driven inspection, supported by better data, automation, and analytics.

Robotic crawlers now enter boiler interiors and turbine casings with ultrasonic and electromagnetic sensors,

reducing dismantling and human exposure. Automated eddy-current systems inspect thousands of heat-exchanger tubes in a fraction of the time once required, with greater consistency. In nuclear plants, radiation-hardened robotics and remote manipulators reach areas humans simply cannot.

These are not futuristic experiments. They are operational necessities.

Seeing More Clearly, Deciding More Confidently

Advances in ultrasonic and radiographic techniques have changed how inspectors “see” components.

Phased-array ultrasonic testing now delivers volumetric images of steam turbine rotors, pressure vessels, and reactor internals allowing inspectors to visualize defects rather than infer them. Time-of-flight diffraction improves crack sizing confidence where fitness-for-service decisions depend on millimeters. Advanced radiography provides higher resolution with faster interpretation, even in thick sections.

Eddy-current testing, long trusted for condenser and steam-generator tubing, has evolved into a more quantitative tool supporting degradation modeling instead of simple pass/fail judgments.

The result? Fewer false alarms. Fewer missed threats. Better conversations between inspectors, engineers, and asset owners.

The Quiet Rise of Continuous Integrity

Perhaps the biggest change isn’t in how inspections are performed but when.

NDT is steadily moving away from isolated inspection events toward continuous integrity management. Sensors monitoring vibration, temperature, wall-thickness loss, and even neutron flux now feed digital platforms that track asset health in real time.

This matters because power generation today operates under intense pressure. Outage costs are high. Fuel prices fluctuate. Regulatory expectations continue to rise. In this environment, unplanned shutdowns are not just technical failures, they’re financial and reputational ones.

Reliable inspection data allows operators to plan maintenance intelligently, justify life-extension decisions, and avoid reacting to failures after the fact.

Reliability Is No Longer Optional

For nuclear operators pursuing license renewals, inspection evidence must be comprehensive and defensible. For fossil plants balancing retrofit costs against replacement, inspection data guides investment decisions. Even during decommissioning, NDT plays a critical role helping classify materials, manage risk, and ensure safe transitions.

Across the lifecycle from operation to life extension to retirement NDT is the common thread holding decisions together.

From Inspection Data to Insight

What makes modern NDT truly powerful isn’t just better

equipment or faster inspections. It’s the ability to turn raw signals into understanding.

Today, NDT informs risk assessments, supports regulatory compliance, protects public safety, and keeps critical infrastructure running in an increasingly complex energy landscape. It allows operators to extend asset life with confidence or to say no when limits are reached.

As grids evolve, renewables expand, and baseload plants shoulder new responsibilities, the future of power generation will depend as much on how we maintain existing assets as on how we build new ones.

And in that future, NDT won’t be the loudest voice in the room but it will be the one everyone listens to.





The Growing Importance of NDT in Power Plant Operations

As power generation assets age and operating demands rise, non-destructive testing has become central to safety, reliability, and life-extension decisions. This article explores how modern NDT—driven by data, automation, and continuous monitoring—is reshaping inspection strategies across fossil and nuclear power plants.



he security of contemporary power systems is pegged on the security of assets that produce, transform, and convey power. For decades, the electricity industry has depended on heavy industrial infrastructure including steam turbines, boilers, nuclear reactor parts, condensers, pressure vessels, critical piping, and rotating equipment to have the electricity flowing. With the increased demands of the operating environment, as these assets get older, inspection and condition evaluation has become the cornerstone of safety, regulatory compliance, and operational survival. The core of this fact is Non-Destructive Testing (NDT) that can be considered the main way of how operators can check the health, monitor the degradation, and prolong the service of the object without interrupting functioning.

When it comes to the fossil power industry especially in coal-fired and gas-fired thermal power plants, turbines, boilers and superheaters, they are exposed to high temperatures, cyclic stresses, and corrosive conditions which over time cause gradual initiation of fatigue, creep, and corrosion-related failures. Components within and surrounding the reactor pressure vessel in the nuclear industry experience even more complications through the neutron irradiation, thermal gradients and stringent requirements of the safety case.

Although the two industries vary in terms of design ideologies, and legislation, they have one thing in common, and that is, the weakness should not go undiscovered, and failure should not be accepted. NDT has traditionally made this possible with a peephole view into the state of the assets that does not involve dissection or dismantling of the assets.

Historical methods of inspection were mainly manual and periodic. The technicians conducted regular ultrasonic checks, eddy-current tests, radiology, magnetic tests or dye penetrant tests on the identified components during planned maintenance periods or plant shutdowns. Such periodical snapshots were good at discovering some kinds of flaws, but they necessarily had gaps between the inspection periods.

Thermal Plants constructed in the 1970s and 1980s and nuclear plants now needing extensions of their licenses are under increased scrutiny as the operators strive to determine how to maintain the assets over the decades beyond the expected lifespan at their design. With a growth of equipment life beyond 30 to 60 or even 80 years, the asset integrity will cease to rely on fixed maintenance rates or restrictive assumptions.

The development of NDT in power generation is similar to the overall energy transformation trends, as data, sensors, robotics, and sophisticated analytics are changing the way of how inspections are conducted and the way of decision-making. Robotic crawlers with ultrasonic and electromagnetic inspection systems can now be used in steam-cycle plants to access interiors of boilers and turbine casings to locate and examine internal surfaces with limited dismantling. Automated eddy-current systems are used to check the scale of heat exchanger tubes minimizing downtimes and enhancing defect detection reliability. The remote manipulators and radiation hardened robotic platforms are allowing inspections in un-friendly conditions in nuclear plants where the human touch is limited. These are innovations that are minimal in personnel exposure, cost reduction in cases of outages, and the magnitude of assets that can be analyzed within a limited shutdown period.

The accuracy of detection is being redefined by the acquisition of digital data and better imaging procedures. Phased-array ultrasonic testing is used to produce volumetric images of rotors of steam turbines, pressure vessels and reactor internals which are more detailed whereas advanced radiography techniques are used to give higher resolution images of rotors and pressure vessels with shorter interpretation time. Eddy-current testing, which has traditionally been used on condenser and heat exchanger tubes, is becoming more quantitative in a shorter time period, making it possible to predictively model the tube degradation with progression of time. Both industries have seen these inspection improvements as crucial to enable the operators to make a more effective distinction between the

non-threatening signs and the deficiencies with potential of crack-initiation or growth.

These advancements have more than speed and accuracy in terms of inspection. With the increasing role of in-service monitoring, NDT is moving away from periodical assessment and more towards continuous integrity management. Vibration, temperature, wall-thickness loss, or neutron flux sensors are supplying digital platforms that offer real-time insights into the behavior of components.

Having such tools, the operators of the plants will be able to predict the degradation rates, optimize their maintenance plans and minimize the risks of unplanned shutdown. This solution is very much in line with the economic realities of the power sector, where outage control, fuel prices and regulatory obligations assume high operational and financial burdens.

The operators of nuclear plants have adopted these trends as the renewal of licenses and life-extension plans continue to spread around the globe. To increase the lifecycle of reactors, there has to be very strong evidence of the pressure vessel structural integrity, piping circuits structural integrity, steam generators structural integrity, and reactor interiors structural integrity.

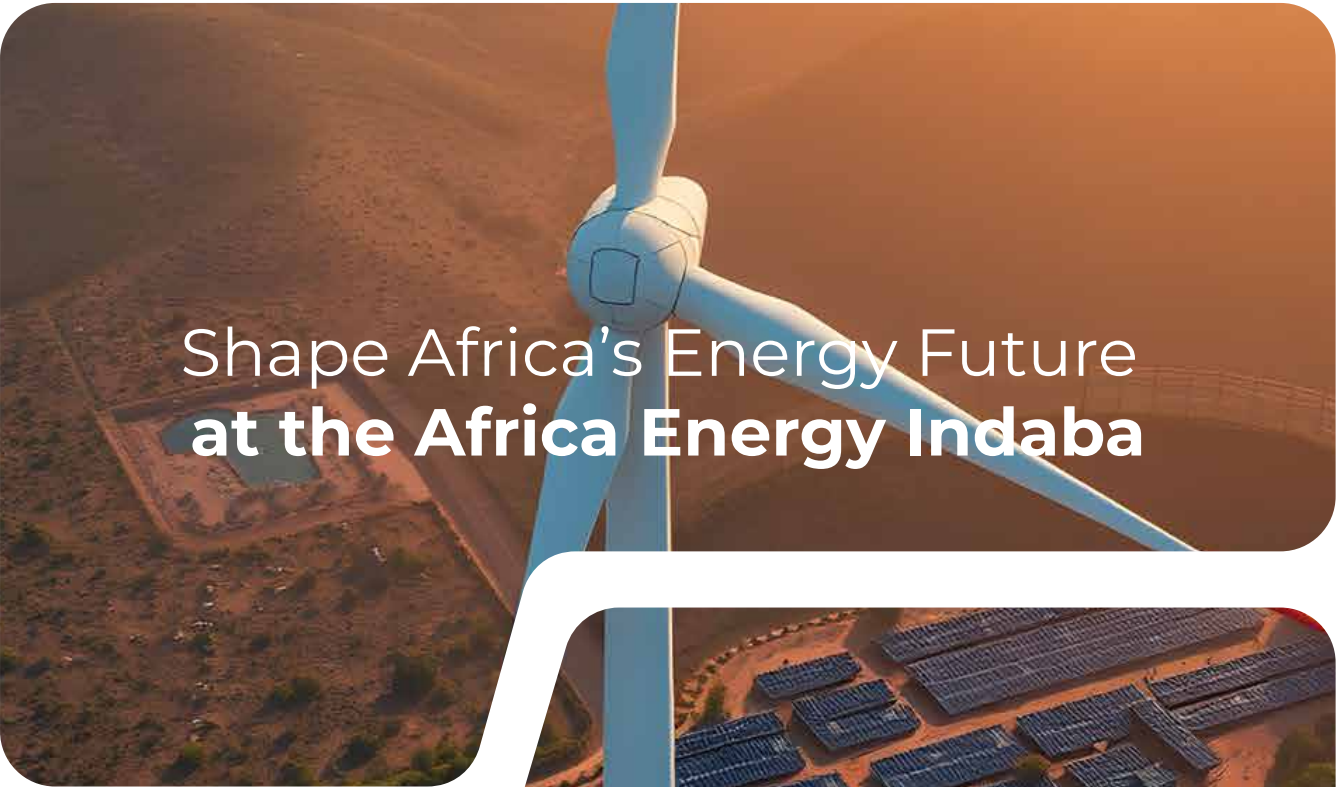
NDT is a determining factor in recording that the materials that have been irradiated, thermally overstressed, or

corrosion-assisted in cracking are still within acceptable limits. The same life-extension pressures are manifested in fossil plants in the form of utilities balancing the cost of substituting older thermal units with retrofitting them to operate more efficiently or to cycle higher. In both scenarios, superior inspection and monitoring give situational awareness in order to warrant further operation.

Besides operation, NDT is also a conclusive aspect at the expiry of a given asset. The nuclear decommissioning programmes are based on the inspection to describe the structural elements, categorize the waste products, and facilitate safe decommissioning. Fossil plants being phased out or converted to alternative energy consumption need the same type of evaluation to ensure the risk is appropriated and the remaining asset value maintained. At these latter stages of life-cycle NDT makes sure that transitions are safe and within the rigid environmental and regulatory frameworks.

Due to the changing nature of the global energy environment, the need to have reliability, resilience, and low-risk operation is increasingly becoming important. Integrity and uptime is a non-negotiable requirement regardless of whether one is backing up baseload nuclear units or flexible fossil plants balancing renewables. The industry is also shifting away from reactive problem solving to informed decision-making, which is possible due to advanced NDT, improved digital data, robotics, and predictive analytics. The future of the power industry lies in not only the new generation technologies, but also in the maintenance and optimization of the large infrastructure that is already present.

The unique significance of the contemporary NDT is that it can convert raw inspection data into practical intelligence. NDT gives operators the evidence-based knowledge to extend their assets, minimize risk, regulations, and ensure public confidence through evidence-based insight into component condition, degradation mechanisms, and lifetime performance. The further development of inspection methods, together with the digital revolution and the better quality of integrity control allow keeping both the fossil and nuclear power base operating safely and reliably as the grid increases in complexity and the demands on the performance level rise.



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Expert Talks

The Long Road to Getting Inspections Right: Anmol Birring's NDT Journey



Anmol Birring
President at Birring NDE Center, Inc.

In this exclusive conversation with OnestopNDT, Mr. Anmol Birring shares insights from more than four decades at the forefront of advanced NDT—spanning research at Southwest Research Institute, hands-on industrial application across critical assets, large-scale global consulting, and training thousands of professionals worldwide. His journey reflects the evolution of modern NDT and highlights how curiosity, practical understanding, and continuous learning shape true technical expertise.”

Mr. Birring, welcome to OnestopNDT. It's a privilege to have you with us. Could you begin by sharing your professional journey—from your early research work at Southwest Research Institute to your leadership roles as President of Birring NDE Center, Inc. and President at NDE ASSOCIATES, INC., and your current work as a global consultant in advanced NDT?

After graduation from IIT Delhi in 1978, I went for higher studies to Iowa State University. During the course of my work, I stumbled on ultrasonics and did my Master's Thesis on surface/Rayleigh waves. Thereafter, I went to Southwest Research Institute (SwRI) in San Antonio, Texas. At SwRI, I worked for a variety of clients including the US Navy, Electric Power Research Institute (EPRI), Association of American Railroads, Chevron, Bofors, RenuSagar Power and many more. The focus of my work was on developing ultrasonic techniques for a variety of problems including corrosion assessment, boiler inspections for hydrogen damage and creep, wear measurement, high-temperature hydrogen attack, turbine inspections, etc. After ten years at SwRI, I worked at an electric power company, Houston

Lighting and Power. This is where I got hands-on practical experience in all NDT methods as applied to boilers, steam lines, turbines, feedwater heaters, condensers, etc.

You began your career developing NDT techniques at a time when many of today's advanced methods were still evolving. What initially drew you to non-destructive testing, and what kept you deeply engaged in this field for over four decades?

What drew me to this field & kept me engaged is that NDT is a problem-solving field where you can develop techniques to solve problems faced in the industry to assess damage & avoid failures. This is one field where the rewards are immediate. You develop a technique, test it, refine it, apply it, and see the results of your work. This makes it very satisfying.

Your career spans research, field application, training, and consulting. How has your perspective on NDT evolved as you moved from hands-on research to qualifying advanced inspection systems for critical assets worldwide?

The research and practical

experience gave me a good foundation on the application of NDT, whereby I not only know the basics of the techniques but also their limitations. This is when you not only think of applying a NDT method but also understand its reliability. Reliability starts to play a bigger role as you not only want a working method but also the right method. Reliability is not only dependent on the method but involves the whole process of application including technique, calibration, scanning, & finally the technician. The NDT technician plays a pivotal role in the application of NDT methods.

You have been closely involved in high-risk damage mechanisms such as high-temperature hydrogen attack (HTHA) since the late 1980s. From your experience, what are the key challenges in reliably detecting such degradation mechanisms, and how has NDT progressed in addressing them?

I have been involved with high-temperature hydrogen attack (HTHA)

since the early eighties when a Japanese engineer put HTHA pipe samples on my desk at SwRI and said we need to find an NDT method. In the beginning, we used velocity ratio for HTHA inspections. It was not until the late eighties that we discovered that HTHA results in backscatter. During the course of my work, I went to sites that had HTHA failures and conducted follow-up inspections. That is where I realized the implications of HTHA failure can be very serious. HTHA failure is not the same as a boiler tube failure which is contained in the boiler. HTHA failure can result in severe injuries and even fatalities so it has to be taken seriously. In conclusion, I can say the technique has to be very reliable, otherwise you are giving a false sense of safety. I have done several HTHA inspections in the US and other countries and did find one reactor with HTHA. HTHA was verified and the reactor taken out of service immediately after the inspection. This was in France.

Over the years, you have developed and qualified inspection techniques for complex applications—ranging

from heavy-wall welds and alloy weld inspections to microstructural assessments. What role does probability of detection and sizing accuracy play when qualifying advanced NDT methods for real-world applications?

There are many steps involved in qualification and a lot depends on the specific application. For example in case of stainless weld inspections, the calibration block should include a weld that is representative of production weld. Scan plans correctly designed to detect expected discontinuities. Proper selection of phased array probes and focusing to improve sizing. Similarly for HTHA you need sample with real microstructural damage & finding such samples can be a challenge. POD, probability of detection is directly dependent on the outcome of the failure. High POD inspections are a must where failure can have serious consequences. These include subsea piping, high pressure steam lines, HTHA, aerospace, etc. Let us not limit discussion to advanced NDT and/or





complex applications. I will go back to manual UT of carbon steel welds using conventional angle beam probes. Even for this simple application, I normally am able to qualify 30 to 40 percent of Level II techs. Most fail because of poor training.

You have worked extensively with advanced ultrasonic techniques such as phased array, TOFD, automated UT, and backscatter methods. In your view, what differentiates a well-qualified advanced NDT application from one that merely uses advanced equipment?

Advanced equipment does help in developing techniques. But more important than equipment is having a good understanding of the physics of the method.

With experience supporting major operators such as ExxonMobil, Shell, BP, and Qatar Energy, how do you approach balancing inspection reliability, practical constraints, and operational realities when advising clients?

In addition to the above list, I have also worked with many other clients including Total (France), Boeing, South Texas Nuclear Plant, Chevron, EPRI, Southern Peru, Mitsubishi (Japan), and many more. What is most important when working with clients is transparency. We have to understand client needs and limitations. We have to offer reliable and practical solutions that are applicable.

Having published over eighty technical papers, how important is technical

documentation and knowledge sharing in improving inspection practices and preventing repeat failures across industries?

Technical publications and making presentations keep you at par with the scientific community. As you know, the first step in writing a publication is to search for other relevant work. That exercise keeps you informed on what is going on elsewhere. Technical publications distribute information and, in turn, you also gain information.

Training has been a major part of your legacy, with more than 5,000 professionals trained globally. From your perspective, what are the most critical gaps in NDT training today, especially when it comes to application-specific inspections?

Good question. Technicians play a key role in NDT. Training includes lectures and practicals. What is most important in training is to communicate at a simple level and give real-life examples so that it is easy for the students to grasp the concepts. The goal is to understand a method and not just pass the test. What is usually lacking in training are the practical skills. Students should be trained on samples with representative flaws.

You have conducted NDT training and consulting assignments across multiple countries and cultures. How does regional variation—in standards, asset conditions, or skill levels—impact the way NDT is applied and qualified globally?

I have done training in several countries but never had language issues as everyone understands Math and Physics. It is the duty of the instructor to make training interesting by using diagrams and giving practical examples. It is global training that motivated me to add NDT videos since I used to be

limited in performing practicals during some off-site locations. I have almost sixty videos on my YouTube channel that cover all methods of NDT. Videos include both lectures and practicals. Viewers of my videos are from all over the world and send me regular feedback. Some training schools also use my videos.

As a senior leader and mentor in the NDT community, what advice would you offer to young engineers and inspectors who want to move beyond basic certification and develop true technical authority in NDT?

I can recommend two things. One is to be diverse and be familiar with all NDT methods and not just specialize in a few. Secondly, learn about materials and processes such as welding, heat treatment, etc. Also be familiar with relevant engineering codes. And finally, you must gain hands-on experience to gain confidence.

Outside of your professional work, how do you like to spend your time when you step away from NDT? Are there any hobbies or personal interests that help you recharge or provide a different perspective from your technical work?

I do a lot of garden work. I have mastered the skill of growing tomatoes and cauliflower. I start from the seed and all the way to final production. Again, there is a lot of science involved and I learnt it at Rice University, Houston.

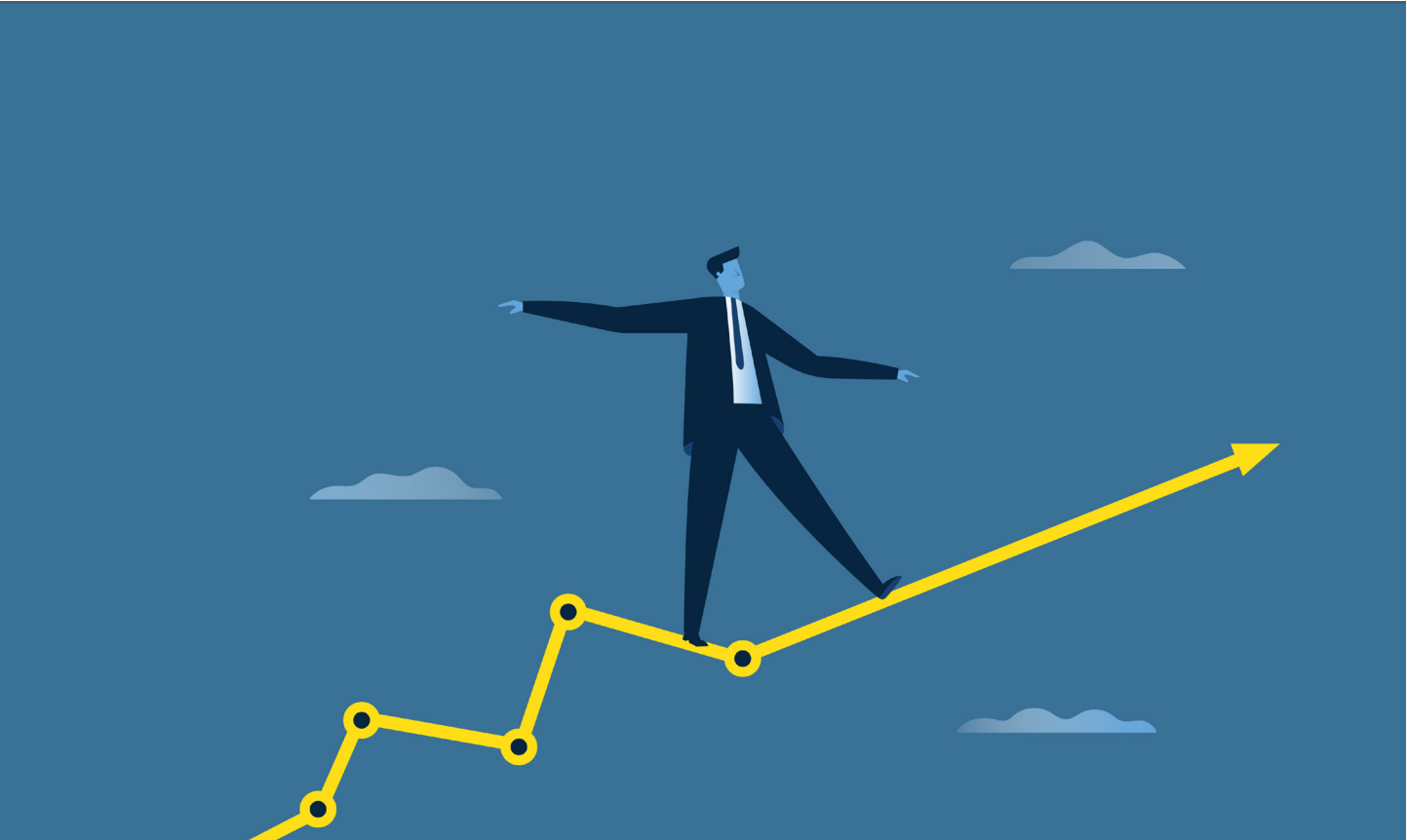
Looking ahead, what developments or shifts do you believe will most significantly influence the future of advanced NDT applications and inspection reliability over the next decade?

Like everyone says, AI will start to play a role in all fields including NDT. However, so far AI has not been successful in

interpretation with either UT of welds or radiography. So a lot needs to be seen. I believe human interpretation will still remain primary.

Finally, Mr. Birring, as someone deeply involved in NDT education, application, and industry advancement, how do you view platforms like OnestopNDT? Do you see value in such platforms for knowledge sharing, professional connection, and supporting the next generation of NDT practitioners?

These are good platforms that spread information and bring the community together. I suggest you have live video interviews. You have a good forum for open discussion. You should visit colleges and universities to bring more awareness of NDT and bring more women into NDT.





Expert Article

Why Advanced NDT Is Non-Negotiable in the Nuclear Industry?

In

Nuclear power plants, failure is not an acceptable outcome. Safety-critical components such as the reactor pressure vessel, reactor internals, primary coolant piping, steam generators, and associated pressure-boundary welds operate under extreme conditions of high pressure, elevated temperature, neutron irradiation, and service lifetimes that often exceed original design assumptions. At the same time, many nuclear plants are getting older, running for longer than originally planned, and facing stricter regulatory checks. Because of this, inspection results must be highly reliable. In this scenario, Advanced Non-Destructive Testing (NDT) techniques are essential for nuclear safety, equipment health, and uninterrupted plant operation.

While conventional inspection methods laid the foundation for nuclear quality assurance, modern plants rely heavily on advanced ultrasonic, radiographic, and electromagnetic techniques to detect,

characterize, and size defects with high confidence. The following techniques are applied strategically across reactors, piping systems, and pressure vessels to manage risk and support informed engineering decisions:

- » Ultrasonic Testing
- » Phased Array Ultrasonic Testing
- » Time of Flight Diffraction
- » Eddy Current Testing

Let's look into detail at these advanced NDT Techniques used in the inspection of Nuclear Power Plants.

Ultrasonic Testing (UT)

In ultrasonic testing, high-frequency sound waves are sent into a material using a probe placed on the surface. These sound waves travel through the material and reflect back when they hit boundaries such as cracks, voids, inclusions, or the back wall of the component. The reflected signals are received by the probe and displayed on an instrument screen, where trained inspectors interpret them to identify and locate defects.

In simple terms, ultrasonic testing works like medical ultrasound, but instead of imaging the human body, it checks the internal health of metals and other solid materials.

Conventional Ultrasonic Testing remains one of the most widely used inspection methods in nuclear facilities due to its ability to penetrate thick sections, detect internal flaws, and be deployed in both fabrication and in-service conditions. UT is routinely applied to reactor pressure vessels to identify laminar defects, hydrogen-induced damage, and manufacturing anomalies that could compromise structural integrity. In piping systems and welds, it is commonly used to detect lack of fusion, inclusions, and service-induced cracking mechanisms.

Ultrasonic testing in nuclear plants is not always straightforward. Many components are made from materials like austenitic stainless steel or dissimilar



Jefy Jean Anuja Gladis
SCHRADER Verfahrenstechnik GmbH
Technical Sales Manager

metal welds, where the sound waves do not travel smoothly. This can make signals harder to read and easier to misinterpret. To get reliable results, inspectors must carefully choose the right probe, use suitable beam angles, and calibrate the equipment on realistic test samples. In the end, the skill and experience of the inspector are crucial for telling real defects apart from background noise in the material.

Next let's move to a further advanced method of Ultrasonic Testing which is PAUT.

Phased Array Ultrasonic Testing (PAUT)

Instead of using a single sound beam like conventional UT, PAUT uses a probe made up of many small elements. These elements can be fired in different sequences, allowing the sound beam to be steered, focused, and scanned electronically. This makes it possible

to inspect a component from multiple angles without moving the probe much.

Phased Array Ultrasonic Testing has significantly advanced nuclear inspection capabilities by enabling electronic beam steering, dynamic focusing, and rapid scanning from a single probe position. This flexibility makes PAUT effective for inspecting complex weld geometries and thick-section components such as reactor coolant system welds, pressurizers, and reactor pressure vessel nozzles.

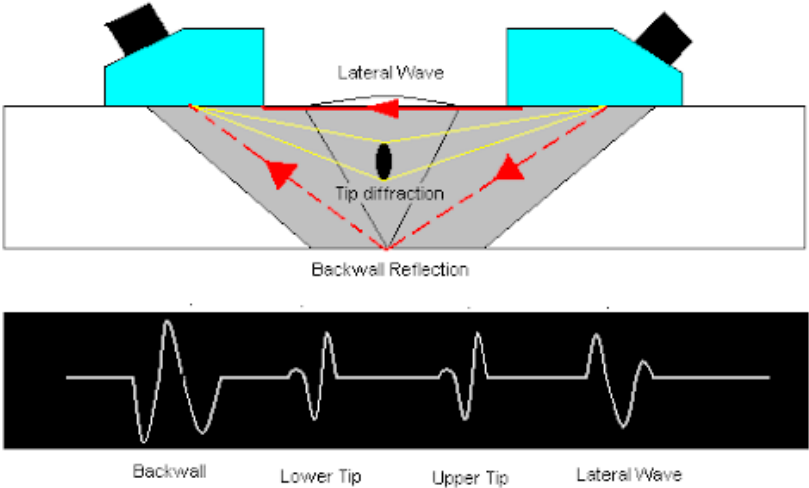
PAUT works by scanning a component from many angles at the same time, which makes it easier to find flat defects such as stress corrosion cracking and thermal fatigue cracks. It also allows inspectors to save and review complete inspection data, making results easier to trace and repeat which is an important requirement in nuclear plants. However, PAUT is not a technique that can be used without preparation. In nuclear applications, inspection procedures must be carefully qualified under

standards such as ASME Section XI or ENIQ, and the data must be analysed by experienced inspectors who can correctly interpret complex signals without mistaking harmless indications for real defects.

Time of Flight Diffraction (TOFD)

Time of Flight Diffraction (TOFD) is an advanced ultrasonic testing technique used to detect and accurately size cracks and other defects inside materials without causing damage.

In TOFD, one ultrasonic probe sends sound waves into the material while a second probe receives them on the opposite side of the weld or component. When the sound waves hit the tips of a crack or defect, they are diffracted and picked up by the receiving probe. By measuring the time it takes for these diffracted signals to travel, the exact position and height of the defect can be calculated.



TOFD is especially valued because it measures defect size based on crack tip signal, not signal strength. This makes it more reliable for sizing defects, even when their orientation varies. In industries like nuclear power, TOFD is widely used for inspecting welds in pressure vessels and piping, where accurate defect sizing is critical for safety and life assessment.

In simple terms, TOFD focuses on the edges of a crack rather than how loud the echo is, which is why it is trusted for precise flaw sizing.

Time of Flight Diffraction is valued in nuclear inspections primarily for its superior flaw sizing accuracy. Unlike conventional UT, which relies on signal amplitude, TOFD detects diffracted signals originating from the tips of defects. This makes it less sensitive to defect orientation and particularly effective for determining through-wall crack height.

In nuclear power plants, Time of Flight Diffraction (TOFD) is mainly used for inspecting welded joints in safety-critical pressure boundary components, where accurate flaw sizing is essential for structural integrity assessments.

One of the most common applications of TOFD is the inspection of reactor pressure vessel welds, particularly circumferential and longitudinal welds in thick sections. These welds must meet extremely strict

acceptance criteria, and TOFD is used to accurately measure crack height and through-wall extent during fabrication inspections, periodic in-service inspections, and plant life-extension programs.

TOFD is also widely applied to primary and secondary piping welds, including welds in reactor coolant systems, surge lines, main steam lines, and feedwater piping. These welds are prone to degradation mechanisms such as thermal fatigue and stress corrosion cracking. TOFD provides reliable sizing data that supports fitness-for-service evaluations and helps engineers decide whether a detected flaw can remain in service or requires repair. However, TOFD has limited sensitivity near component surfaces and is therefore commonly deployed alongside PAUT to ensure comprehensive volumetric coverage.

Eddy Current Testing (ET)

In eddy current testing, a small coil carrying an alternating electric current is placed close to the surface of a metal. This current creates a changing magnetic field, which in turn induces tiny circular electrical currents called eddy currents in the material. When these currents encounter defects such

as cracks, corrosion, or wall thinning, their flow is disturbed. This disturbance changes the signal picked up by the probe, allowing the inspector to detect and evaluate the defect.

Eddy Current Testing is indispensable for inspecting conductive materials where surface and near-surface degradation mechanisms dominate. In nuclear power plants, ET is extensively used for steam generator tubing inspections to detect pitting, wear, and stress corrosion cracking. It is also applied to heat exchanger tubes and other thin-walled components where rapid screening and high sensitivity are required.

Advanced ET techniques, including array probes and rotating pancake coils, have enhanced coverage and defect characterization capabilities. For ferromagnetic materials, remote field eddy current testing enables effective inspection despite material permeability. Successful ET inspections depend on careful probe selection, frequency optimization, and experienced interpretation, particularly in environments where multiple degradation mechanisms coexist.

Integrated NDT Approaches

In nuclear inspection programs, no single NDT method is relied upon in isolation. Regulatory bodies and plant operators increasingly expect integrated inspection strategies that combine complementary techniques to improve detection confidence and reduce uncertainty. Pairing PAUT with TOFD for weld inspections, supplementing UT with ET for tubing assessments, or confirming fabrication results using both RT and UT are now standard practices. This multi-technique approach provides a more complete understanding of component condition and supports defensible engineering decisions.



Conclusion

Advanced NDT techniques form a critical pillar of nuclear power plant safety and reliability. UT, PAUT, TOFD, and ET each offer distinct advantages, and their intelligent application across reactors, piping, and pressure vessels ensures structural integrity throughout a plant’s operational life.

For NDT professionals working in the nuclear sector, success requires not only technical expertise but also a deep understanding of inspection limitations, qualification requirements, and data interpretation challenges. As nuclear plants continue to age and performance expectations rise, advanced NDT will remain central to sustaining safe, reliable, and long-term nuclear operations.

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Flaw sizing with plane wave imaging (PWI) – total focusing method (TFM) and deep learning for reactor pressure vessel

Gonçalo Sorger, Iikka Virkkunen, Christer Söderholm

Abstract

Developments in machine learning and deep convolutional networks (CNNs) have enabled automated assessment of nondestructive evaluation (NDE) data. Ultrasonic data is especially challenging for automated evaluation due to its complexity, multi-channel nature, and volume. Typical flaw signals have a low signal-to-noise ratio, particularly diffraction signals critical for sizing. This study presents a proof-of-concept on the application of deep CNNs, specifically U-net and Swin-U-net, for flaw sizing in ultrasonic data from a nuclear test block with realistic flaw simulations. The segmentation CNNs extract flaw signals, enabling the identification of the deepest crack tip echo, mimicking human inspection. This mimics the process used by human inspectors. Two distinct CNNs are trained: U-net and a transformer-based Swin-U-net. A novel data reconstruction method is proposed that combines plane wave imaging (PWI), synthetic aperture focusing (SAFT) and total focusing method (TFM) to provide a unified volume reconstructed view. Both networks provide good segmentation performance, allowing accurate sizing, despite noisy data and complex flaw signals.

1. Introduction

Nondestructive evaluation (NDE) is used extensively in the nuclear industry to maintain and confirm continued reliable

and safe operation of mechanical structures [1,2]. The effectiveness and reliability of NDE is paramount and there has been significant research and investment into confirming NDE reliability. Ultrasonic testing (UT) is particularly relevant and challenging. While the richness of UT data can be harnessed to enhance inspection capabilities and performance it also makes the interpretation of complex data challenging. Improved procedures, qualification, increased mechanization and moving to technologies like phased array (PA) ultrasonics [3] have significantly improved to NDE reliability. At the same time, longstanding issues have remained relevant and even made worse by some of these developments. NDE data analysis is still laborious, difficult, and prone to human error, which is aggravated when the amount of data increases [4,5]. In this context, artificial intelligence and machine learning (AI/ML) can enhance the reliability of inspections through comprehensive interpretation of vast amounts of inspection data, a task that is beyond human capability. The further integration of digital tools and AI/ML is a critical enabler of NDE 4.0, the ongoing step-change or “revolution” in NDE systems and use [6–8].

1.1. Advances in NDE signal processing

Recent developments that combine different methods for insonifying a region of interest (ROI) with digital focusing have improved the performance of UT systems. Some emerging digital signal processing methods, like the total

focusing method (TFM) [9–12], phase coherence imaging (PCI) [13–15], and plane wave imaging (PWI) [16,17] offer the opportunity to further enhance NDE capability and provide better data for flaw characterization and sizing [18,19]. Additionally, the use of ultrasonic signals, wavelet analysis, and significance testing has enabled the separation of structural noise and flaw echoes in metallic materials, further enhancing flaw detection capabilities [20]. Innovations such as adaptive time-frequency filtering and ultrasonic array transducers, have contributed to the enhancement of flaw detection in various materials, including stainless steel structures and composites [21]. These advancements have led to the development of novel approaches for improving the ultrasonic inspection of materials, emphasizing the continuous evolution of ultrasonic NDE techniques for flaw detection and sizing.

1.2. The challenges of high-volume data in NDE

The new NDE technologies have increased the amount of data to be analyzed. While this improves the data and technical performance of these methods, it also makes data evaluation more challenging and may increase potential for human errors. Data analysis can be a tedious and time-consuming task. Human inspectors are susceptible to errors due to fatigue and environmental factors [22–24], and performance can vary for different inspectors [25]. While recent research has provided tools for quantifying detection [25], the methodology for quantifying sizing performance is still relatively undeveloped [26]. Flaw sizing in NDE presents several major challenges due to the diverse nature of materials and the complexities involved in flaw detection. One of the key challenges is the need for accurate and reliable flaw detection in critical components of systems such as nuclear power plants, and pipelines [27]. Furthermore, the effectiveness and accuracy of flaw sizing methods are crucial for ensuring the safety and integrity of structures, where ultrasonic NDE techniques play a vital role in detecting, locating, and sizing potential flaws [21].

1.3. Flaw sizing

Different methods have been used for sizing flaws from UT signals [18]. Amplitude based sizing methods, such as the 6 dB drop method, have been industry standard but are limited and unreliable in the case of real cracks with irregular surfaces, often resulting in under or oversizing [28–30]. Other sizing techniques such as distance amplitude correction (DAC) and distance gain size (DGS) rely on the comparison of measured signals with reference signals from known reflectors. As such, sizing accuracy depends strongly on the similarity between the real flaws and the known reflectors, which in most cases is unrealistic [31,32]. So far, the most reliable methods for sizing of real cracks are those that are

based on correctly identifying and locating diffraction signals from crack tips [15,33–35]. These are sometimes challenging due to the low amplitude of the tip signals and uncertainties related to the correct tip identification, particularly in noisy materials.

1.4. Automated flaw detection

Recent work on machine learning (ML) for NDE [36–41] makes it possible to automate the difficult data evaluation, reducing the risk of human errors, and increasing the consistency and efficiency of inspections [42]. Although machine learning has shown success in complex classification tasks its use remains limited due to a lack of representative flawed datasets for training. For ultrasonic testing the relevant flaw characteristics include: location and orientation; size; opening through the whole path and at crack tip; fracture surface roughness; and whether it is filled with some substance [31]. It has also been demonstrated that ML generalization is different for different artificial flaws, solidification cracks, EDM notches, and simple simulated flaws [43]. Fortunately, data augmentation techniques have had recent success in providing synthetic or virtual flaws with sufficient quality for model training [44–48].

Different ML architectures have been successfully applied to NDE tasks. Examples in defect detection include support vector machines [49, 50], random forest algorithms [51–53], or autoencoders [54]. Moreover, the success of deep neural networks in various cognitive tasks has raised expectations for the application of ML in ultrasonic testing data interpretation in the non-destructive evaluation (NDE) field [55]. Recently, convolutional neural networks (CNN) have become the method of choice for tasks like image classification, object detection, and segmentation [56,57]. The integration of machine learning with ultrasonic data has shown potential in improving flaw detection and classification. Studies have demonstrated the use of neural networks to classify various flaw types, such as cracks, slag inclusions, porosity, and artificial flaws from ultrasonic signals, highlighting the potential for machine learning in enhancing flaw detection capabilities [43,58,59]. CNNs have been increasingly utilized in the field of ultrasonic testing [60]. CNNs are particularly preferred for processing two dimensional ultrasonic data and have been found to be effective in ultrasonic flaw classification, even in noisy conditions [58]. CNN-based ultrasonic image reconstruction has also been proposed as an approach for improving ultrafast acquisition [61], and several studies have demonstrated the effectiveness of CNNs in processing ultrasonic data to locate, and identify flaws from UT data [43,59,62].

1.5. Towards automated flaw sizing

Recently progress has been made also on ML-based flaw

sizing and characterization. Latete et al. [63] explored the use of CNNs to locate, identify, and size defects in phased array ultrasonic testing (PAUT). Similarly, Pyle et al. [64] achieved defect sizing by training a dense neural network on raw ultrasonic data and proposed a method for improving the interpretability of the results [65], as well methods for quantifying their uncertainty [66]. Bai et al. [67] compared the performance of Bayesian inversion and CNN-based ML approaches on the characterization of small surface-breaking cracks, concluding that there are limitations regarding the characterization of unfavourably oriented defects. Guo et al. [68] combined CNN and wavelet transform to automatically analyse the laser ultrasonic signals for detecting the width of subsurface defects. Bevan et al. [51] explored how different ML models can be applied to the problem of immersion inspection with ultrasonic phased arrays and demonstrated that ML tools adequately distinguish between pristine and defect samples, as well as between defect types and sizes, although the defects studied did not have the features of real flaws.

Still, classical CNNs struggle with capturing long-range dependencies (i.e. relationships between elements in a sequence that are far apart, such as in large, complicated features) in the input data, which is a crucial aspect in image recognition and classification tasks. This can be a significant limitation, especially when dealing with limited or low signal quality datasets. In contrast, transformer-based models [69] have shown effectiveness in addressing these limitations associated with CNNs, achieving comparable or better performance with fewer parameters, making them more computationally efficient. Simultaneously, the self-attention mechanism in transformer-based models excels in capturing long-range dependencies, allowing them to process sequences without being limited by the receptive field size (i.e. the area of input data that a neuron can “see”), thus providing an advantage over CNNs in some image recognition tasks. This could be advantageous in NDE applications, particularly when the task requires long range pattern matching such as segmenting the whole indication when it’s composed of several distinct peaks.

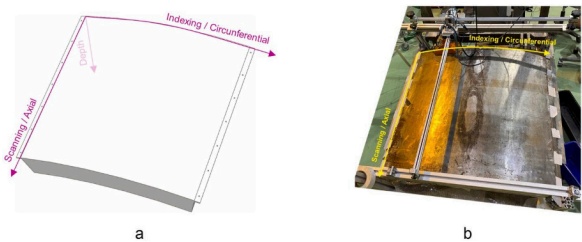


Fig. 1. Mock-up with coordinate system. Schematic representation (a); and real mock-up with probe and probe movement system (b).

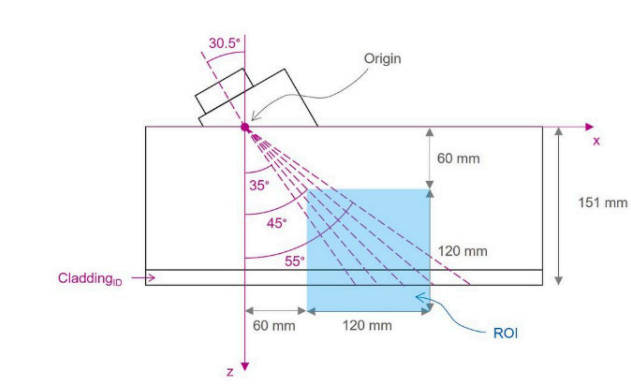


Fig. 2. Schematic representation of the probe and wedge set-up. The plane waves were shot at 35°, 40°, 45°, 50°, and 55° angles. The reconstructed region of interest ROI is 200 × 200 voxels.

1.6. Data acquisition and digital reconstruction

Conventional PAUT applies beamforming both in transmission and reception. Electronic beamforming is performed directly in the hardware, according to pre-calculated focal laws, typically using the delay-and-sum (DAS) technique [70]. The beam may be “planar” or focused at specific points in the target volume. Because of the pre-determined focusing points, PAUT can suffer from limited lateral resolution and contrast, and loss of resolving power with increasing distance from the focusing point. To overcome these issues several alternative beam forming methods have been put forward, mostly originating in medical UT applications. For the inspection of solid materials, factors such as mode conversion, or the effect of complex microstructure must be considered, but the working principles of these algorithms still apply. Spatial filtering techniques based on spatial spectrum estimation [71, 72] can improve resolution and suppress interference from unwanted direction but are sensitive to covariance estimation and can be computationally complex. Variance based methods [73–76] excel at rejecting interference while enhancing the desired signal but might be sensitive to estimation errors or noise. Adaptive beamforming methods [77–79] dynamically adjust to changing conditions and are effective at suppressing interference in dynamic scenarios but can be slow to converge and continuous adaptation and parameter updates can introduce computational overhead. A version of DAS that performs the multiplication of combinatorially coupled signals before the summing step, called delay multiply and sum (DMAS) [80], enables higher contrast resolution though at the cost of amplitude loss away from the transmission focal depth.

The superposition of elemental signals works for wide range of different inspections, even when the elemental signals are separate in time and never superimposed in the

physical material [81]. A set of reconstruction techniques takes this approach and excite and acquire separate elemental signals independently and then compute reconstructed data in post processing. The primary benefit of these techniques is that the focusing can be easily computed throughout the insonified volume, and various advanced focusing and contrast techniques can be applied to further optimize the inspection. The potential drawbacks include more computationally intensive data processing and a large volume of acquired data.

To achieve focusing at every point in a ROI the target is insonified with multiple waves. Although implementation details may vary, the digital focusing (DF) algorithms for UT mostly share the same working principle from a conceptual point of view [13,14,16,82,83]: a region of interest is discretized into a grid of pixels/voxels and the intensity of each pixel/voxel is determined by the coherent summation of the contribution from different signals that insonify the pixel/voxel from different directions. The various embodiments of this working principle differ in how the target is insonified, and how the contributions to the intensity in each/pixel and voxel are calculated exactly [83].

One of the first such algorithms was the synthetic aperture focusing technique (SAFT). Originally developed to improve the capabilities of radar systems, SAFT has been applied to ultrasonic testing since the late 70’s [81,84,85]. Each element works in pulse-echo mode and the data/image reconstruction for a point in a grid in the ROI is obtained by the coherent summation of the data sampled from each elements’ pulse-echo signal [86,87]. Other methods,

using more than one element on receive can provide high resolution, though at the cost of processing time [82,88]. Full matrix capture (FMC) [9,89,90] is a data acquisition technique where the data from all possible transmit-receive element combinations on a phased-array probe is captured, providing a comprehensive dataset that enables detailed analysis and imaging of the target. Processing the complete matrix of collected data requires significant computational power [83,90,91]. Methods such as plane wave imaging (PWI) [16,17] and sparse array acquisition [92] mitigate these issues by reducing the number of transmit events without significant reduction of imaging quality if the parameters are adequate.

In the present study, we present a proof-of-concept on the application of deep convolutional neural networks (CNNs) to provide sizing on plane wave imaging/total focusing data obtained from a nuclear test block with realistic flaw simulations. We combine PWI with TFM and SAFT to generate high quality reconstructions of a region near the inner diameter of a reactor pressure vessel (RPV) wall mock-up with embedded artificial flaws. We then use these images to train a state-of-the art Swin-U-net model [93] to detect and size defects in the mock-up.

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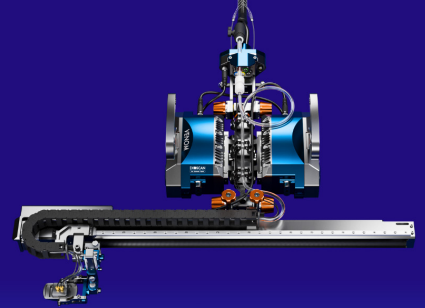


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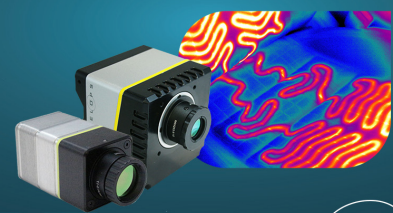


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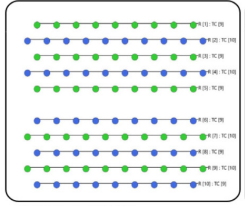
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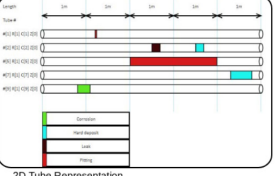




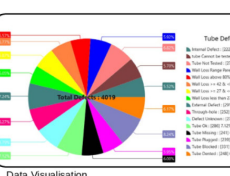
Pre-Inspection Craft Mode



TMR Final Tube Inspection Report



2D Tube Representation



Data Visualisation

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