NDE 4.0 and a paradigm shift in blade integrity management

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Join us for an exploration of the rise of Industry 4.0 and NDE 4.0, the role that acoustic emission (AE) condition monitoring plays in shifting the focus of blade integrity programs, and a glimpse of what the future of blade integrity might look like with the adoption and proliferation of these new technologies.

The concept of Industry 4.0 has been around for a little over a decade and has already had a massive impact on the way the world operates. Whereas earlier industrial revolutions brought about the rise of mechanisation, then mass production, and later computing and automation, the fourth industrial revolution is leveraging an increase in computing power to create an unprecedented web of interconnectivity and business intelligence across industrial processes.

It has been described as: 'The fourth revolution is not a discrete event; it is a phase over which the suite of cyber-physical technologies is coming together to change the way humans work and live, produce and consume, learn and stay healthy.'[1] In short, the world is digitally transforming.

Occurring alongside this transformation is the evolution of non-destructive examination (NDE) technologies that both incorporate elements of and serve as a connective component of Industry 4.0, in a shift called NDE 4.0. As digital technologies mature as part of the fourth industrial revolution, the rise of Industrial Internet of Things (IIoT)-connected online condition-monitoring technologies, like Sensoria™, an innovative 24/7/365 wind blade monitor from MISTRAS Group (NYSE:MG), is transforming traditional blade inspection and maintenance decision-making practices. This has additional implications for the role that integrity data can play in blade design optimization and predictive performance analytics.

Blade integrity management within NDE 3.0

The first two decades of the 21st century saw incredible advancements in NDE technologies. Tremendous reductions in the size of electronic instrumentation, advancements in unmanned robotic technology, and exponentially-increased computing processing capabilities made possible the commercial deployment of powerful NDE systems.

These enhancements resulted in higher-resolution data that could be collected quicker than ever before, but the actual inspection process, along with the transfer, integration, and analysis of blade integrity data, continued to operate from a more reactive, siloed orientation.

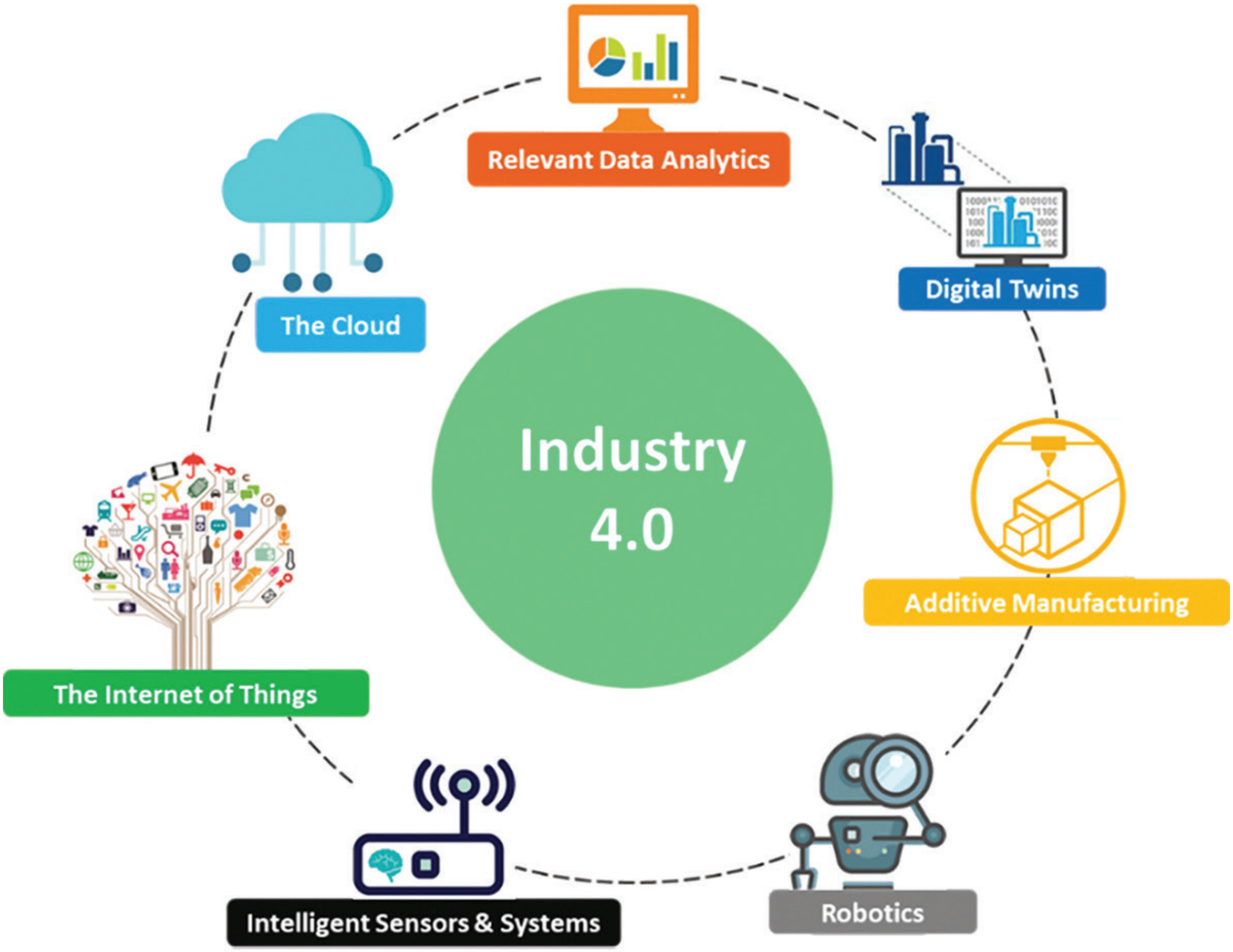
The standard industry practice to determine blade integrity involves conducting manned or drone-based visual inspections at predetermined time intervals, usually ranging from a few months to up to three years. These inspections generate visuals that are confined solely to what blades and damages looked like at the time of inspection. This allows damage to form and/or worsen in between scheduled shutdowns, reducing generating capacity and often resulting in higher maintenance costs.

As wind energy operators seek ways to meet the ever-growing demand for wind energy production and as the number of wind turbines at individual wind farms that require regular inspection stretches into the thousands, there is a clear need to mature these practices alongside the rise of Industry 4.0.

A philosophical shift from static to dynamic

Recent industrial and technological advancements are not only streamlining the acquisition of blade integrity data, but enhancing data analysis and cross-functionality to better inform inspection and maintenance decision-making.

Elements of the fourth industrial revolution that are enabling greater computing power,



Industry 4.0 refers to the marriage of physical assets and advance digital technologies. NDE 4.0 technologies like the Sensoria™ wind blade monitor can play a key role in generating business intelligence based on real-time condition monitoring

Big Data analytical capabilities, relatively ubiquitous internet connectivity, and inexpensive data storage are also being incorporated into the latest generation of NDE technology.

As this shift towards NDE 4.0 occurs, the latest technologies have a few technical capabilities in common, dependent upon the system's place along the spectrum of evolution. These include on-board data processing; cloud connectivity; remote software and firmware updates; machine learning/artificial intelligence/predictive analytics; integration with virtual reality; and cybersecurity.

Just as Industry 4.0's marriage of the cyber and physical spaces is evolving the way that the world lives and works, NDE 4.0 technologies are enabling us to reimagine the way that integrity data can be used to maximise asset uptime and productivity. The evolution that's underway is empowering a shift from the traditional, reactive, fixed-interval-inspection philosophy towards a proactive, condition-based integrity paradigm.

Acoustic emission blade condition monitoring

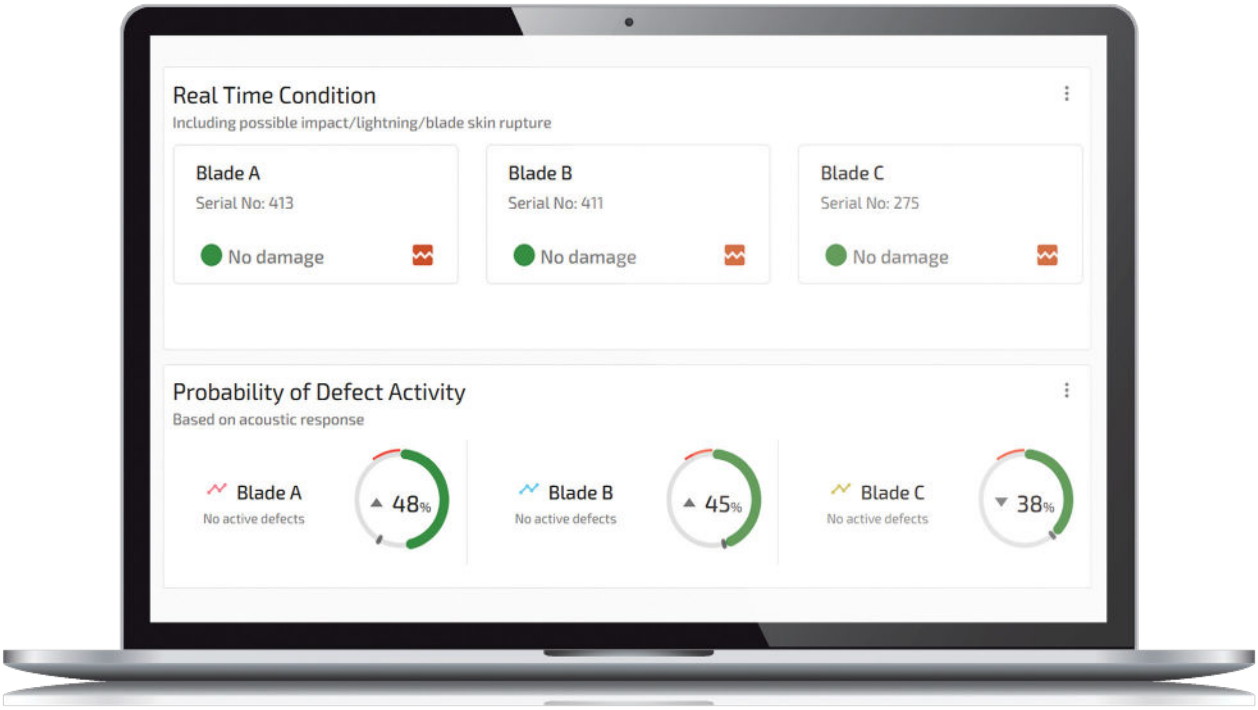
Rather than fixed, semi-annual inspection schedules, NDE 4.0 is leveraging online monitoring systems that detect and communicate information on asset conditions in real time.

Condition-monitoring systems are common in many industries, including defence, aerospace, and oil & gas, to guide and optimise inspections and repairs. The wind energy industry already uses condition-monitoring systems on drive trains, towers, and foundations for both onshore and offshore turbines. These systems monitor for specific, well-known conditions and have been commercially available in some cases for decades.

However, IIoT-capable monitoring systems for wind turbine blades, such as the Sensoria™ wind blade monitor, that can remotely detect cracking, delamination, impacts, and other damages are a new innovation that can help in the constant search for better alternatives to traditional NDE inspections, and to improve the Operation & Management (O&M) of these crucial renewable energy assets.

The implementation of NDE 4.0 technologies require a continuous stream of data from permanently-installed NDE sensors, and correlations with real-time operational data. Acoustic emission technology is particularly suited to meet the needs of a condition-based philosophy of integrity management, as the large amounts of real-time data that it produces is conducive to be utilised within the context of modern computing power. MISTRAS Group has been a leader in acoustic emission monitoring for decades, and the company's systems have proven to be effective in monitoring integrity conditions of civil infrastructure and other traditional power generating assets.

Today, AE instrumentation has evolved to the point that it has built-in communications modulus for internet access via Wi-Fi and cellular, including 5G, networks, which enables data accessibility to users via a Data-Driven Web Application, and AE data integration with operational and weather data affecting the assets[2]. In the case of Sensoria™, the system



NDE 4.0 technologies like Sensoria™ collect real-time integrity data and report it through an online, easily-accessible data portal, enabling wind turbine operators to proactively plan their inspection and maintenance activities based on the actual conditions of their assets

consists of three Micro Electro-Mechanical System (MEMS) AE sensors, one per blade, a powerful AE data acquisition system (AE-DAQs), and a cloud-based Data-Driven Web Application (DDWA).

Once the acoustic data is collected and transferred to the cloud, processing is completed in the DDWA, where proprietary Structural Health Quantities (SHQ) for the blades are calculated and used to guide the inspection and maintenance decision-making process. The DDWA also provides visualisation, interpretation, blade acoustic activity ranking, real-time alarm communication, trending, reporting, and data archiving for individual blades and full wind farms.

Incorporating NDE 4.0 into Industry 4.0: a vision for the future

NDE 4.0 technologies are one piece of the Industry 4.0 puzzle. The digital transformation being brought about by Industry 4.0 enables collaboration amongst previously-siloed industries and technologies that can have hugely beneficial impacts on blade design and performance. One notable example is through the use of digital twins.

Digital twins are virtual representations of physical assets that incorporate real-time operational data, machine learning, and artificial intelligence to enable users to replicate behaviours from their real-world counterparts to predict possible outcomes.

Specifically for the purpose of wind blades, digital twins enable the integration of blade condition-monitoring system data with design, test, inspection, maintenance, and performance data to predict and help improve blade behaviour, integrity conditions, and generating capacity.

Whereas traditional inspection practices require operational shutdowns and manual inspections to identify even if damage is present, a blade's digital twin could enable wind turbine operators to detect damages in real time and predict the impact of various rates of degradation on short- and long-term blade productivity, creating an exponentially more informed and timelier integrity program. Digital twins can play a crucial role in these efforts, as they enable a direct, symbiotic feedback loop between design and operating data.

In the long term, as NDE 4.0 monitoring technologies become further enmeshed in wind energy operations and as Industry 4.0 continues to create more opportunities for digital, collaborative infrastructure, a possibility begins to take shape for not just a digital twin of an individual wind turbine, but for a complete digital wind farm, incorporating models of nacelles, drivetrains, towers, foundations, transformers, and more, integrated with the relevant operational data.

1 Vrana, J.L., & Singh, R. (2020). NDE 4.0 From Design Thinking to Strategy. arXiv: Other Computer Science.

2 Godinez-Azcuaga, V., Ley, O., Nunez, A., Lowenhar, E. &; Kattis, S. (2022). From NDE 4.0 A Natural Step for Acoustic Emission. 35th European and 10th International Conference on AE Testing. Ljubljana, Slovenia.

The vision for a future with fully-digital wind farms presented here is still in the distance, but the evolution towards a condition-based approach to blade integrity management built upon NDE 4.0 technologies is fully underway.

With IIoT condition-monitoring systems like the Sensoria™ wind blade monitor, wind turbine owner-operators can transform their approach to blade integrity management from static to dynamic, from reactive to proactive.

As the world continues to increase its reliance on wind energy generation, these technologies will be crucial in improving blade generating capacity and maximising blade value.

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