FMC User Group

Online meeting (MS Teams)

1 August 2024, 4.00-5.00PM

Present

Online: Abdeldjalil Bennecer, Tom Bertenshaw (TB), George Connolly, Xiaosong Du, Larissa Fradkin (LF), Baptiste Gauthier (BG), Nathan Gurrin-Smith, John Jian, Katherine Kirk, Pei-Yen Liao, Dave Lines, Philippe Rioux, Andreas Schumm (AS), Jonathan Taylor, Ray Ten Grotenhuis, Adri van de Biggelaar (AB), Paul Wilcox (PW).

Minutes of last meeting[1]

Summary and status of actions:

- Common file format
  - Disseminate dictionary to this group when complete (AS) – **DONE**[2]
  - Put presentation given at ASNT Research Symposium 2023 on FMC User webpage (PW) – **DONE**[2]
  - Produce whitepaper on philosophy of MFMC format for discussion (PW) – **ON HOLD**[3]
  - Complete MFMC Python library with documentation & examples (PW) – **ON HOLD**[3]
- All to continue to suggest speakers / topics – **DONE**, offers received from
  - Larissa Fradkin, "FMC and Explainable AI for damage characterisation" (this meeting)
  - Tom Bertenshaw, title TBC (next meeting)
  - Paul Wilcox, "Laser-induced phased arrays and selective matrix capture" (reserve for future meeting)
- PW to organise next meeting – **DONE**.

Chair's update

PW reported that discussions in the FMC User Group about file formats had been superseded by the *UT Data Common File Format* initiative led by Terrill Massey at EPRI, which included many members of the FMC User Group. The *UT Data Common File Format* initiative now comprised four sub-groups:

- Data structures (Andreas Schumm, EDF) – general approaches to data storage and structure
- Transducer Information (Baptiste Gauthier, Evident Scientific) – data describing transducer
- Trajectory (Tyler Lesthaeghe, UDRI) – data describing scanning path
- Information Subgroup (Terrill Massey, EPRI) – other data to be included in file

Each sub-group has now met twice, once in March and once in July this year.

PW's view was that the outcome would depend heavily on how the participants in the *UT Data Common File Format* initiative view the purpose of a common file format:

- For short to medium term storage and retrieval of data driven by vendors and current users, the likely outcome would be a format based on current use-cases with relevant engineering data stored explicitly in the file; a consequence of this would be a format that required relatively frequent updates to accommodate new use-cases, probes, scanning patterns etc.

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[1] https://www.bindt.org/branches-and-committees/User-Groups/ [note address has changed]

[2] Shared via EPRI 'Box' site of *UT Data Common File Format* initiative

[3] On-hold pending outcomes of *UT Data Common File Format* initiative

- For long-term archival, the likely outcome would be a file format based on the most general description covering all current and conceivable future use-cases with engineering data only recorded implicitly; this approach would lead to a format that would be expected to change very rarely, if at all and in PW's opinion would be likely to lead to something similar to the MFMC format, since it was designed on this basis.

AS commented that the tensions between the two were recognised but remained confident that a consensus on a format that satisfied both purposes could be reached. The dictionary document mentioned in the last meeting and available to users of the EPRI Box fileshare summarised the common features and differences between the EPRI format, ECUF v1, and MFMC v2.

TB asked about how closely the format was linked to ISO standard 23865:2021 (Non-destructive testing — Ultrasonic testing — General use of full matrix capture/total focusing technique (FMC/TFM) and related technologies). PW noted that Casper Wassink (member of the FMC User group) had been involved in developing that standard. AB noted that he had worked on another relevant standard, ISO 23243:2020 (Non-destructive testing — Ultrasonic testing with arrays — Vocabulary).

Presentation "FMC and Explainable AI for damage characterisation"

Prof. Larissa Fradkin of Sound Mathematics Ltd. gave the above-titled presentation to the group. Presentation slides are appended to these minutes.

FMC and Explainable AI for Damage Characterisation

AUTONDE (AUTOMATED NON-DESTRUCTIVE EVALUATION) PACKAGE

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Motivation

- Faulty energy infrastructure can result in large revenue and indirect losses. Here is a particular example: three out of France's 56 nuclear reactors have been shut in January 2022 because of the cracks near welds on their safety cooling systems. That led to loss of over 6% of the France's nuclear capacity. In the last quarter of 2022, because of faulty wind turbine components Siemens Gamesa made a loss of €472 M.
- Regular NDT&E (Non-Destructive Testing & Evaluation) inspections significantly reduce the likelihood of major accidents. However, the industry faces shortage of suitably qualified NDT personnel, and their assessments are not 100% reliable, particularly, due to fatigue when analysing large volumes of data.

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Motivation (ctd)

In addition to direct financial losses associated with **unplanned outages**, NDT failures can also lead to indirect costs:

- **Extra repair costs**
- **Lost productivity**
- **Reputational damage**
- **Regulatory fines**

Approximate annual loss in revenue due to NDT failure per typical two unit nuclear plant	**$4.5 M** Frost & Sullivan (2021) The Costs of Inaction: Leaving Nuclear Power Plant Profits on the Table

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Motivation (ctd)

Approximate annual loss in revenue due to NDT failure per typical off-shore wind farm	**£50K[1]*$200MW/pa$[2] *0.6[3] (unplanned maintenance) = £6 M** [1]R Wisera,, M Bolingera, E Lantz (2019) Assessing Wind Power Operating Costs in the United States: Results from a Survey of Wind Industry Experts [2]UK Offshore Wind (2022) International Trade Administration. [3]EC Harris Built Asset Consultancy (2012) Offshore Wind Cost Reduction Pathways

Corrosion and fatigue are the main mechanisms of deterioration of Off-shore Wind Systems

Coatings)**2017**) **https://doi.org/10.3390/coatings7020025.**

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Motivation (ctd)

- The use of artificial intelligence in structural health monitoring (SHM) of large infrastructures is growing due to 1) the availability of big data, 2) the potential for human error, 3) the potential for improving the chances of the early detection of anomalies.
- In parallel, in non-destructive testing (NDT) data collection is also being automated at a large pace. However, there are no reliable large NDT data repositories, so automation of data interpretation is lagging behind.

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AutoNDE

- For several years now SML (Sound Mathematics Ltd.) has been working on accelerating interpretation of NDT data and hence automatic generation of inspection reports and recommendations through the use of AI.
- As there are no good large NDT data depositories, many researchers try to train modern AI tools, such as neural networks, using simulated data.
- SML concentrated on another solution - Expert Systems (custom Decision Trees employing "if ... then" rules and fuzzy logic). Advantages: Decision trees need much fewer training datasets than such solutions as neural networks. They produce easily explainable results. Disadvantages: they are well known to take a very long time to develop.

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AutoNDE

- AutoNDE has been so far trained to characterise fatigue, rough, stress-corrosion cracks and cracks near welds. It can also assess fitness for service of corroded pressure vessels using ASME (American Society of Mechanical Engineers) standards or BS EN. New data would allow for relatively fast development of further options.
- It did so by using innovate UK grants (total value of about £1 M) to train Autonde on quality lab data. The data were quality lab FMC data collected by experts from CEA (the French Commission of Atomic and Alternative Energies), Doosan Power Systems, TWI (the welding institute), Westinghouse and TrueFlaw using phased arrays.

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Similar packages

There are no comparable software packages because custom Decision Trees are expensive to develop, and therefore most current attempts to automate data processing are based on commercial AI products. Companies such as Sentin or Encardio Rite apply AI to SHM (Structural Health Monitoring), when SHM produces big data as a matter of course. What about NDT? There are companies who tried similar solutions: the French company Controle Mesure Systemes has developed software called Probus that speeds up the NDT data analysis and helps technicians to produce inspection reports.. Similarly, Eddify announced working on UltraVision, a software which, like ours is based on the “if ... then” rules. Both companies believe that the volume of NDT work carried out worldwide justifies the development of such products. However, they have found that they cannot afford developing custom Decision Trees that would prove useful to their customers.

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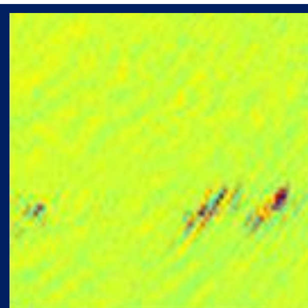
Sample reports on crack characterisation

Fatigue crack

Defect depth = 1 mm
Defect extent = 7 mm
Defect orientation = 90 deg

Report quality = 40 %

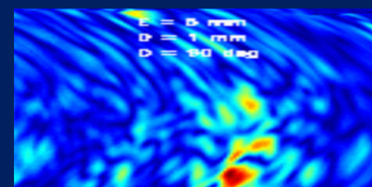
Stress-corrosion cracks



No cracks with measurable through-wall size

Report quality = 90 %

Rough crack



Number of images in group = 39

A possible rough crack is detected.
Defect depth = 1mm
Defect extent - 14mm
Defect orientation = 90 deg

Report quality = 20%

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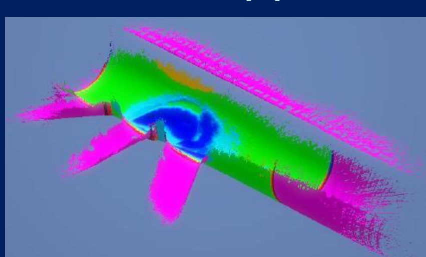
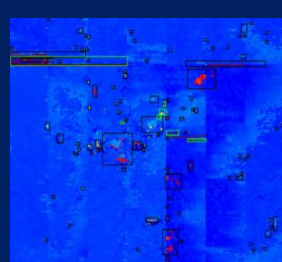
Sample reports on corrosion

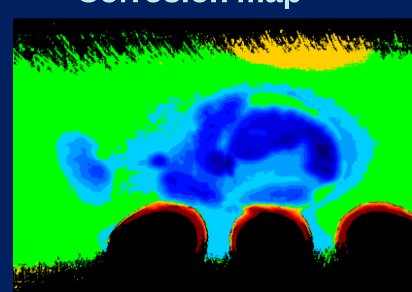
3D Scan of pipework



Composite surface



Corrosion map



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Example of a Report on a Corroded Pressure Vessel

INSPECTION REPORT

Thu Nov 2 10:15:19 2023

INTRODUCTION

Inspection carried out by the CHIMERA system.

APPROACH

Vessel is being assessed against API 579-1/ASME FFS-1 Part 5, however the calculations for the minimum thickness and maximum pressure will be taken from either API 579-1/ASME FFS-1 or BS EN 13445-3 as required. This process is based on a calculated maximum allowable working pressure for the given section of the vessel. Maximum stress values based on the construction material are taken from ASME BPVC Section II-Part D-2015 table 1.a. Thickness profiles are gathered and a level 1 assessment carried out. If the requirements are not met then a level 2 assessment is carried out involving more in depth calculations and values.

ASSESSMENT INPUTS

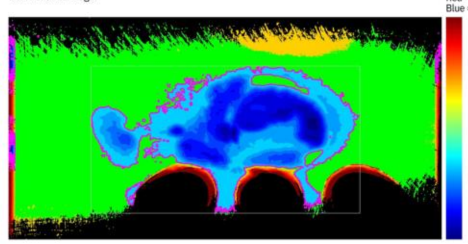
list of inputs to the FFS assessment, based on information supplied by the client.

Working temperature60 (null)
Working pressure300.00 (null)
Type of vessel headsCylindrical shell
Vessel internal diameter173 (null)
Nominal wall thickness (shell)16.0 (null)
Material of constructionSA-516 Grade 70
Weld efficiency factor1.0
NDT DataSee annex B
Desired future operating life

THICKNESS PROFILE 1

Normalised Image

Scale:
Red = 4.4 (null)
Blue = 21.0 (null)



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Next steps

The product is at TRL 6 and ready for beta-testing. Sound Mathematics is looking to **collaborate** with organisations, which could provide **real-life data** to carry out these tests.

Such collaboration would benefit Sound Mathematics by enabling it to assess and improve the performance and usability of the software.

The collaborating inspection service providers could benefit by speeding up their report generation while beta-testing AutoNDE. If they find AutoNDE useful, their future licensing fees would be reduced.

There are also several programmes around that could fund such collaboration.

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Beta-testing of the crack characterisation module

Testing & Improvement

- Access to new PAUT data needed to test AutoNDE performance. Alternatively, images of cracks could be used secured by any other means.
- Training and testing data on cracks near welds would be most desirable.
- Testing data on fatigue, rough and stress-corrosion cracks in cuboids would be desirable but - at this stage - not essential

Performance

- Assess efficiency (speed gain) and effectiveness (probability of detection, accuracy of characterisation) of the software

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Beta-testing of the corrosion mapping module

Testing & Improvement

- New PAUT data are required to test the performance of the FFS_ASSESS module of AutoNDE. Alternatively, corrosion maps obtained by other means could be used.
- AutoNDE can already process data on pressure vessels and pipes. For any other structures, we would first need to code the corresponding inspection standards.

Performance

- Assess efficiency (speed gain) and effectiveness (accuracy of pressure vessels' assessment of fitness for service) of the software

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Automated NDT data processing is the key to increasing productivity and safety in the energy generation industry

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