Workshop on AI for Accelerating Fusion and Plasma Science

IAEA International Atomic Energy Agency

FUSION FOR ENERGY

Artificial Intelligence tools for Manufacturing of the Nuclear ITER Vacuum Vessel

M. Ortiz de Zuniga - Fusion for Energy, 08019 Barcelona, Spain; UNED, Spain

Abstract

Artificial Intelligence (AI) has been applied to many different fields, such as medicine, robotics, linguistics, data mining, decision-making, videogames and the automotive industry, whereas in others it is still to be explored. In general, this is the case of the nuclear manufacturing and fusion, specifically, the case related to **welding success rate prediction** and the **analysis of outputs from the phased-array ultrasonic (PAUT) nondestructive testing (NDT).** The aim of this work is the development and analysis of AI tools for welding success rate prediction and the posterior output processing of PAUT applied to welding defects detection in the ITER Vacuum Vessel manufacturing.

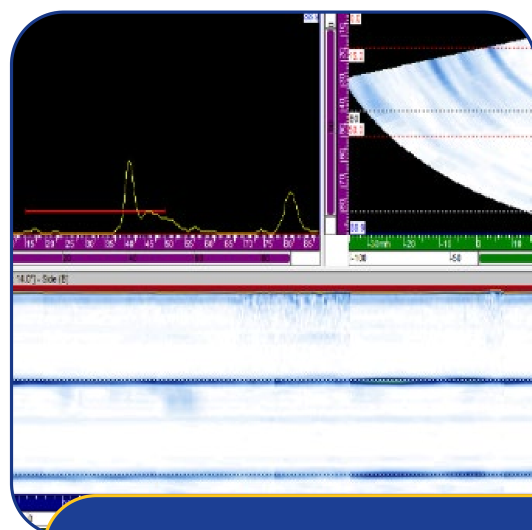
Overview

GB/TAP recommended AI

EB welding
- Success rate prediction
- Real Accuracy: 100%

PAUT for T-welds
- Data processing
- Testing Accuracy: 83%-100%
- Speed improvement: days → minutes

TIG welding of outer shell
- Success rate prediction
- Testing Accuracy: 100%



PAUT for linear Butt welds (outer shell)
- Data processing
- Accuracy: 99.9%
- Speed improvement: days → minutes

Under User-Benchmarking by **F4E resident** and **AMW welding leader** at **supplier** since October-2023

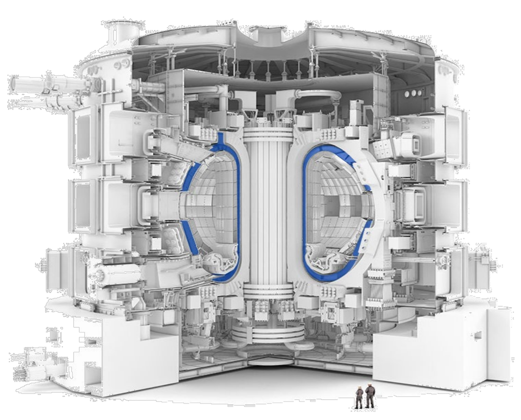
Increasing confidence in AI models for PAUT data processing and welding success rate prediction

The ITER Vacuum Vessel

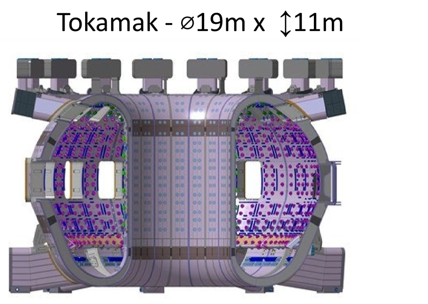
Due to its complexity, the manufacturing of this large equipment - based on the French nuclear design and manufacturing code (RCC-MR) - has generated a large amount of data. Since the Vacuum Vessel is the first confinement barrier of the nuclear fusion installation, ensuring the quality of its welds is a serious challenge. Each of the five European sectors has approximately one kilometer of welding to be performed. Any defect in these welds results in a large disruption on a schedule and on a mechanical level, which has to be recovered, within feasibility limits. A first development of an AI tool to predict weld success rate resulted in a prediction accuracy of Electron beam welding – **EBW** - of almost 100%. This allows the manufacturer and the client to focus appropriate resources, dedicated time and mechanisms in order to improve on the predicted welding rate.

The Vacuum Vessel double-wall nature also results in un-inspectable welds during the last stages of the segment manufacturing on the full weld depth or from both sides through conventional non-destructive testing methods, such as radiographic examination as accepted by the **RCC-MR**; resulting in the need to qualify a more advanced Non-destructive Testing - NDT technique, such as Phased-Array Ultrasonic Testing - PAUT. **PAUT** data processing and interpretation has to be carried out by a human expert and requires one week per weld on average, due to the coarse grain material of austenic stainless steel used in the Vacuum Vessel - **316LN-IG** - and the complexity of the qualified PAUT procedures.

This process is long and costly, affecting performance and requiring a large number of resources noting that the cost of training alone to develop a suitably qualified NDE personnel who can do UT examination can be considerable.



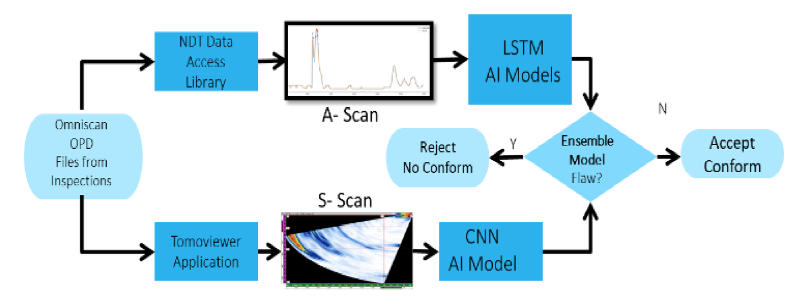
Tokamak - ⌀19m x ↕11m



VV –↕12m x 6.5m wide x 6.3m deep

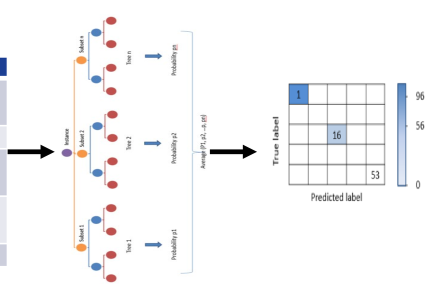
ARTIFICIAL INTELLIGENCE MODELS

Why AI on PAUT for the ITER VV?
- Large amount of historic data
- Large number of parameters
- Long-processing time through other means: human expert, for example.



PAUT Data processing model

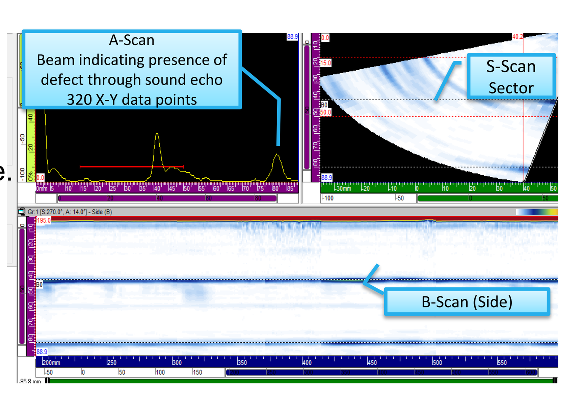
EB Parameters	EB Conditions
Length	Sector/ Segment
Current	Orientation
Welding Velocity	Supplier
Focussing System Current	Type of weld
	Position



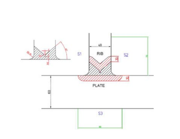
EB welding success rate prediction

PHASED-ARRAY ULTRASONIC TESTING

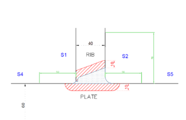
- **UT:** *Type of NDT used to scan welds by using waves at frequencies 2.25MHz for ITER-VV*
- Out of all welds, **full examination of the welded joint** is an essential part for quality class 1 (QC1) welds
- VV double-wall nature → **un-inspectable welds** during the last stages of the segment manufacturing on the full weld depth or from both sides through conventional NDT methods(i.e. RT) as accepted by the code
- Need to qualify a more advanced NDT technique → PAUT
- PAUT can also generate **corrosion mappings**
- PAUT is a type of UT where a number of beams are sent by a probe at an angle, therefore allowing to have better accuracy when these ultrasonic waves bounce back.
- PAUT data interpretation:
  - carried out by human expert
  - Expert must be EN 9712 UT- certified
  - Based on images & comparative assessment of views
- Disadvantages:
  - Long: up to several days per weld due to coarse material (SS 316LN-IG) + complexity of qualified procedures
  - Complex: potential for errors
  - Costly



AI models will use A and S Scans which are selected by moving along the B-scan and recorded every 1mm interval along the length of the weld.

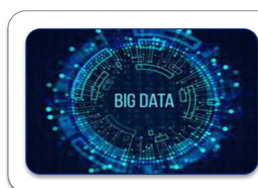


Weld Form B/BB (rib/plate can be 40, 60, 65, 80)



Weld Form C/CA (different accessibility)

SUMMARY



AI models can be built, trained and used to identify the presence of defects in *welds*, finding trends, organizing and classifying welds.

This data processing can **help and direct the human expert** to review PAUT files when deciding on weld conformity.

Data preparation is key in the overall AI model development.

AI models allow for **faster data processing and reduce errors**

A successful AI application for UT has a potential **to save enormous amount of time and money in defect finding**.

AI for weld defect prediction and for PAUT processing can therefore be key in contributing with additional information for projects **to take informed decisions and save time and cost.**

PAUT - AI model	Accuracy
LSTM for A-scan	83%
CNN for S-scan	100%

EB - AI model	Accuracy
True positives	100%
True negatives	100%