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Magnetic Sensors Perspectives in Nuclear NDT field

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Quantum Sensors in the Business
EDF/DSC/DSCI/DQI/DEA – Bernard Sartre NDT Expert

Summary

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Introduction to NDT

- Principles
- Overview of NDT Techniques in power generation

Nowadays magnetic NDT

- Common usage and weaknesses
- Magnetic sensors in magnetic NDT probe technology
- Status of advanced magnetic NDT Techniques

Future of magnetic NDT techniques

- Magnetic NDT Techniques potential applications
- Some specifications for magnetic NDT sensors

Brief sensors specifications

What is NDT ?

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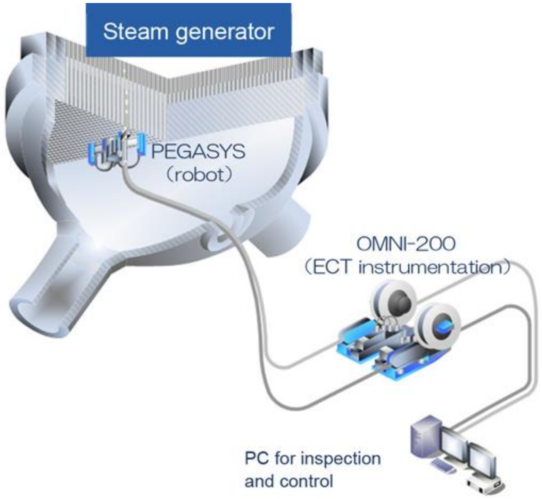
Techniques and operations to assess industrial equipment condition

- Equivalent to diagnosis tools in medicine
- To reveal weaknesses and lack of compliance (services rules and security files)
- In the nuclear industry information gathered with NDT is of main importance for safety plants assessment (pressurized equipment, conventional equipment condition have also to be assess to ensure the best plants available time

Planned at every step of equipment cycle of life

- Material supply
- Equipment manufacturing/assemb'
- On-site installation
- Plant operation
- Dismantling



Machining of a steam generator ferrule

Non-Destructive Testing in Power Generation

Nuclear (EDF)

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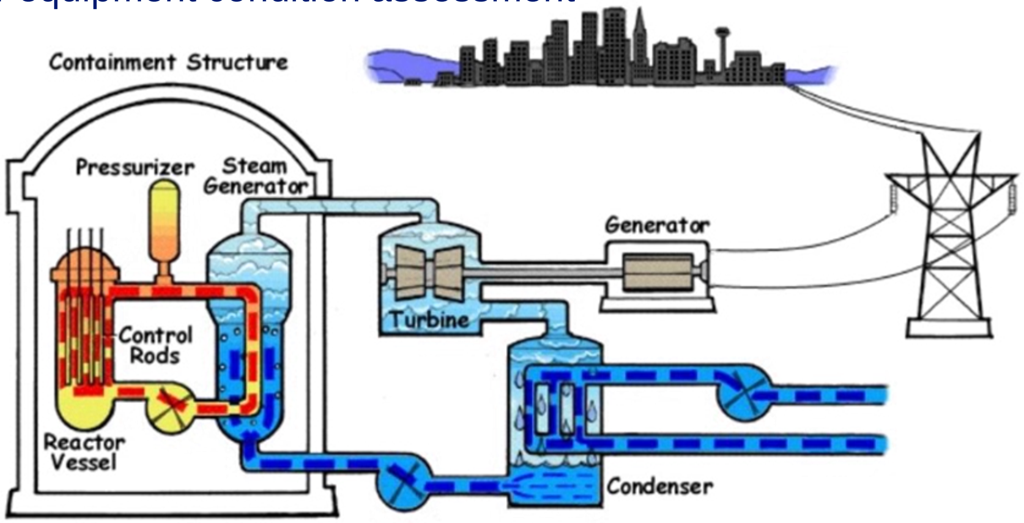
NDT are deployed as part of:

- Nuclear Power and Pressurized Equipment security regulations
- Nuclear Power Plants non-nuclear equipment condition assessment

Nuclear reactor primary loop
- Pressure: 155 bar
- Temperature: 350 °C
- Water: 30 t/s, 25 m/s



The goal is:

- At the manufacturing level: to demonstrate that the targeted design level of security is reach
- In-service before each cycle: to demonstrate that the security files match the regulation requirements

Non-Destructive Testing Techniques

Principles and assumption

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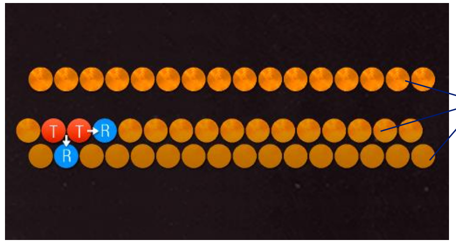
Most NDT techniques rely on:

- A source that created a physical excitation in the medium to be inspected
- An interaction between the excitation and the flaw depending on the material behavior laws
- A sensor that converts the reflected deviation to measurable physical quantity

Then an NDT probe merge sources and sensors

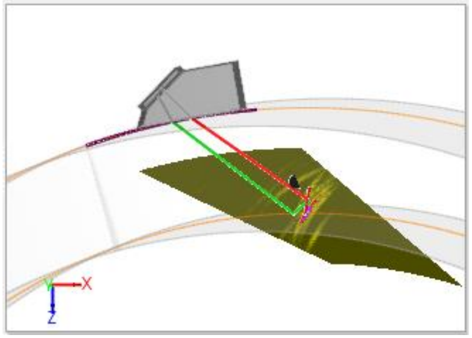
- Note that the same devices could act as source and sensor

Bottom view of an eddy current array probe



Most often NDT techniques are used to detect a deviation from a regular state not to assess material actual condition

- Ultrasonic: no echo
- Radio: Contrast
- Eddy current: Impedance change
- Magnetic particle: Linear feature in the image



Ultrasonic backward echo coming from a planar flaw

Note that most often NDT techniques need scanning from the surface of the part to be inspected

Non-Destructive Testing Techniques

Classification of the main techniques

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	Techniques	Source	Excitation	Manufacturing	In-service
In volume inspection	Ultrasound	Piezo, magnetic actuator, LASER	Mechanical wave	X	X
	X-ray	Tube	Electromagnetic wave	X	
	Particle Beam	Accelerator, Source radio	Particle Beam	X	X
	Acoustic emission	Flaw Constraint release	Mechanical wave		X
Surface inspection	Visual	Light (from IR to UV)	Electromagnetic wave		X
	Eddy current	Coils	Electric current	X	X
	Magnetic Particle	Yoke & coils, magnets	Quasi-static magnetic field	X	
	Microwave	Gunn diode, Magnetron	Electromagnetic wave (free air)		
	Thermography	Light, coils, warm air, …	Heat diffusion	X	
	Penetrant Testing	Colored Liquid		X	X

Electromagnetic Non-Destructive Testing Techniques

Magnetic Techniques Probes Sensors “technologies”

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Techniques	Sensor	Output	Scanning speed
Eddy current (sine)	Coil, array of coils	Impedance / trans-impedance	Up to 2 m/s
Eddy current (pulsed)	Coils	Time related decay points	Max. 100 mm/s
Magnetic Particle	Ferromagnetic particles	2D images	~ 1 m^2/h
Flux leakage	Coils	Time Inductive voltage	Up to 2 m/s
Microwaves	-	-	-

Nowadays common use of NDT probes

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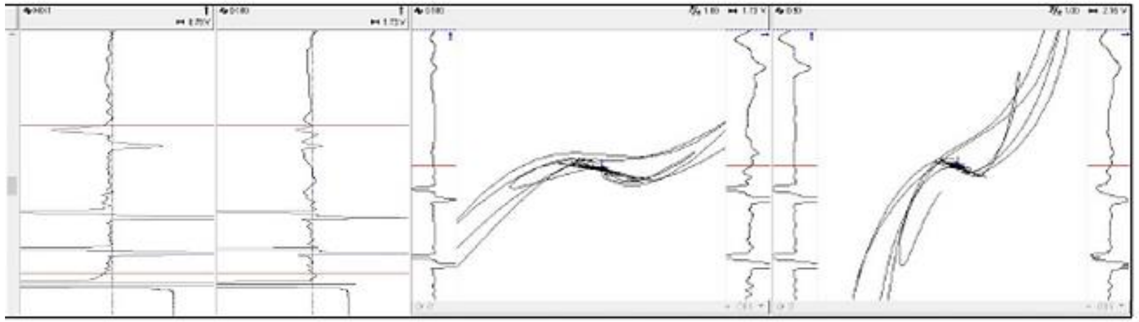
Magnetic particle – Breaking surface flaw image

Probing for a deviation from a standard condition



Typical eddy current signal – Bobbin tube inspection

Weaknesses of these practices

Need of calibration standard (including machined flaws) to set sensitivity and sorting performance of the process

- Costs and design and manufacturing time
- Component representativity and/or repeatability may be difficult to assume
- Main part of the uncertainty, up to 50 % using ET method

Sensitive to local changes of the material and environment properties

Performances too rarely mainly assessed

- Need to ensure that operating conditions are fulfilled
- Not possible when no data is recorded (MT, …)
- Repairing when condition is not clear

No flaw sizing

Possible performances drifts

What future may be made of?

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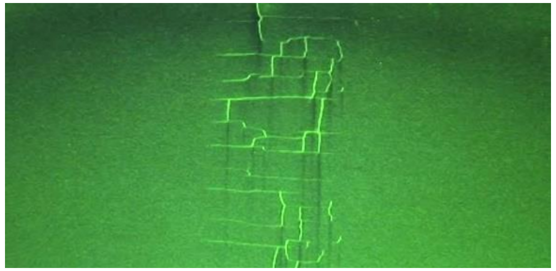
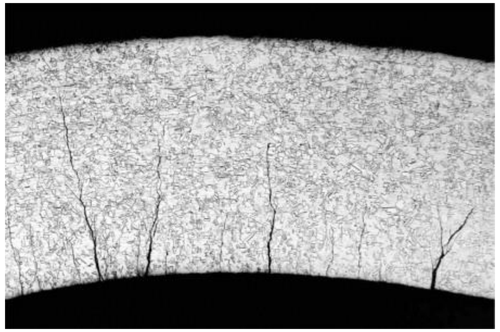
Data suited to be processed efficiently

Data that could be processed in a way to output information more straightly linked to the actual condition of the components (less uncertainty, performance demonstration easier)

Magnetic particles UV image of surface breaking cracks



Section of a tube wall showing cracks



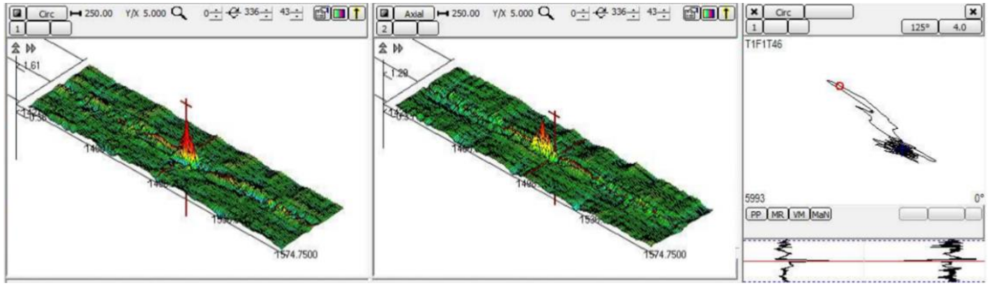
Productivity improvement

More tooling and data recording (according to current strategies)

- Scanning speed increased
- Man time analysis reduced

Extending the magnetic NDT to sizing capabilities

- To do without complementary sizing techniques
- Development of data inversion methods



Eddy current surface scan – Signal 2D drawing to help analysis

Magnetic Particle 2 axis yoke

How magnetic sensors could help?

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Advanced magnetic NDT will heavily rely on array probes

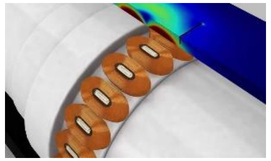
But sensor array are costly

- From some thousand to tenth of thousand €
- Mainly manual coils wiring and assembly
- Must ensure similar performance over all channels
- Small scale machining/mechanics

EC array probe for weld inspection

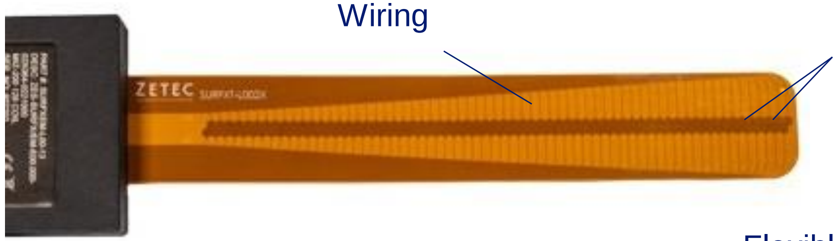
Wiring

EC array probes
for tube inspection



Ways to lower prices

- Sensors must be compatible with mass manufacturing processes and automated assembly for probes manufacturing



Flexible flat EC array probes (weld inspection)

Why not more advanced magnetic NDT in nuclear?

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Few needs issued by utilities, inspection relies on existing products

- Historical techniques prescribed by codes
- Progress driven “new techniques” proposed by suppliers and … by “crisis”
- Magnetic Techniques are supposed to be only able to detect flaw

Potential needs not enough documented

- Data recording
- Dose reduction
- Productivity
- …?

Costs

- Nuclear safety related NDT should be qualified
- NDT operation (mainly operation then NDT equipment and then probes)
- Array probes

Why no more advanced magnetic NDT in nuclear?

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Others

- Lack of numerical methods to process data to extract useful information
- Probe reliability (mainly long cables)
- No techniques of generic uses, new (somewhat advanced) Magnetic NDT Techniques addresses specific and small scope issues
- Long design and development and qualification planning
- Data processing development come at the end of the method development process

But some opportunities exist at least

- High resolution Eddy Current equipment
- Probe size Eddy Current generator

Ways of improvements short list

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No needs of new techniques

By applications

Eddy current on exchanger tubes

- Sizing
- Easier and robust automatic analysis
- Spatial resolution

Eddy current magnetic pipes

- Corrosion imaging
- Wall thickness monitoring

Eddy current surface inspection

- Sizing,
- Productivity (acquisition, analysis)

Magnetic Particle

- Productivity both acquisition and analysis
- Data recording

Electromagnetic Non-Destructive Testing Techniques

Sensors typical specifications

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Sensors		
	Eddy current (conventional)	Magnetic Particle Testing
Frequency of operation	1 kHz to 1 MHz	0 to 50 Hz
Max. magnetic field flux density	100 µT	0.1 - 0.5 T
Resolution	1 nT/√Hz	5 nT/√Hz
Linearity	Some % FS	Some % FS
Drift	< 250 ppm/day	< 250 ppm/day
Temperature coefficient	TBD	TBD

Electromagnetic Non-Destructive Testing Techniques

Sensors typical specifications

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Device (arrays)		
	Eddy current (conventional)	Magnetic Particle Testing
Axis of sensitivity	⊥ & one // to the surface to be scanned	⊥ & one // to the surface to be scanned
Sampling	1000 Hz	1000 Hz (all axis)
Data format	24 bits	12 to 16 bits
Array	2D (/ 3D)	1D / 2D
Array size / sensors	20 x 10 mm	50 mm / 50 x 10 mm
Array shape	Flat / ring	Flat
Spatial resolution	1 mm	1 mm
Distance of the sensors to scanned surface	0,5 mm	< 1 mm
Temperature of operation	10 to 70 °C	10 to 40 °C
Environment	Air/ water	Air

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Thanks for your attention