EM-ReSt.: Elektromagnetische Prüfmethode zur in-line Prüfung von remanenter Spannung und Microrissen in den Lagen bei der Metall Additiven Fertigung mit dem Ziel der Vorbeugung von Fertigungsfehlern

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Kurzfassung

Die Metall Additive Fertigung oder das Auftragschweißen (Metal Additive Manufacturing) (AM) ist eine Fertigungsmethode zur schnellen Fertigung von Prototypen oder kleinen Serien aus Metall, und beinhaltet erhebliche Vorteile für Industriebranchen, in denen die schnelle Herstellung von qualitativ hochwertigen und angepassten Komponenten mit komplexer Struktur von essenzieller Wichtigkeit ist. Die Qualitätsanforderung an die durch AM hergestellten Komponenten, sind, per Definition, hoch, denn sie müssen den speziellen Spezifikationen und Standards der Anwender gerecht werden.

Während der unterschiedlichen Additiven Fertigungsmethoden wie z.B. „selektives Laserschmelzen“ (SLM), „Elektronenstrahlschmelzen“ (EBAM) und „Lichtbogendrahtauftragschweißen“ (WAAM) können remanente Spannung in einer Metalllage oder Microrisse nach der Herstellung zu irreversiblem Schaden und Versagen von Komponenten führen. Sich wiederholende Fehler bei der Materialberechnung oder Parameter-Einstellung führen zu kostspieleigen Verlusten.

Es ist der komplexen Natur des additiven Fertigungsvorgangs geschuldet, dass nicht alle ZfP-Methoden geeignet oder effektiv genug sind, um remanente Spannung und andere Herstellungsfehler in-line zu detektieren. Die neue EM-ReSt.-Prüfmethode kann als „Add-On“ mit in den AM-Prozess eingeführt werden. Die EM-ReSt.-Methode kombiniert EMAT- und Wirbelstrommessverfahren. Das Prinzip wird durch das Auswerten der kumulativen Daten unterstützt, um schon vor der Produktion hervorsagen zu können, wo mögliche Anomalien im Fertigungsteil während der Additiven Fertigung auftreten könnten. Es ist vorgesehen, ein digitales Modell zu erstellen, dass die passendste AM Methode für die bestimmte Form und Komplexität eines Bauteils berechnet, um maximale strukturelle Qualität der AM-Bauteile zu ermöglichen.

(Der Vortrag wird auf englisch gehalten.)

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EM-ReSt-Electromagnetic test method for in-line testing of residual stress and microcracks in the layers in metal additive manufacturing with the aim of preventing manufacturing defects

(Integrating Eddy Current NDT into an Additive Manufacturing Process)

By

John Hansen – Co-Founder and MD ETher NDE

Non-Destructive Testing and Additive Manufacturing (AM)

Normally the issue with Non-Destructive testing of a metal component is to find a defect that is buried within the structure.

Additive manufacturing makes this even more of a challenge due to the complex internal structure.

Such internal structure makes the use of ultrasound extremely challenging and CT X-ray presently is expensive, slow and has radiation safety implications.

However, as these structures are built layer at a time then eddy current could test each layer or even several layers at a time.

The EM-ReSt Project

Much of what follows came out of the Innovate UK EM-ReSt project.

A Strong Team;

ETHER NDE Eddy Current Solutions	SonemaT	HYBRID MANUFACTURING TECHNOLOGIES
Eddy Current	EMAT	DED machines
TWI	INNVOTEK INSPIRING INNOVATION	Brunel University London
Joining Technology and NDT	Creative User interface	Machine Learning

Eddy Current Automation Instruments

✓**For small test Systems ViCTor 2.2d (as AeroCheck+ but with two probe capability and digital and analogue I/O)**

✓**EmbedEC for integration with PC software includes DLL for easy software integration.**

Eddy Current as a CNC Inspection Tool using Hybrid's Ambit

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ethernde.com

AMCheck Eddy Current Unit

- Ether designed a new dual probe ECT system called AMCheck and has released this to market.
- C-Scan capability
- USB data streaming capability
- https://ethernde.com/products/flaw-detectors/amcheck

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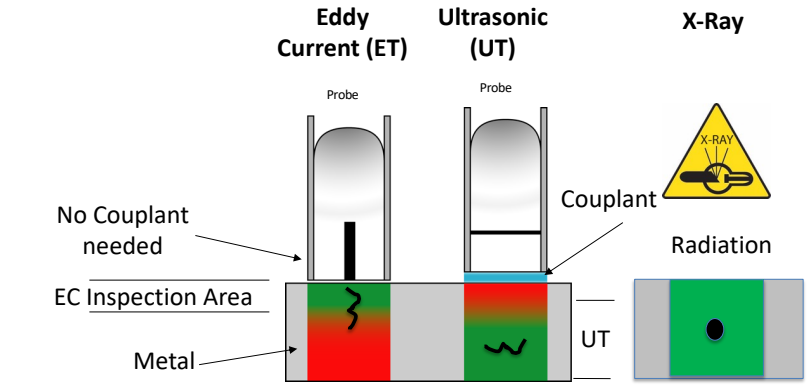
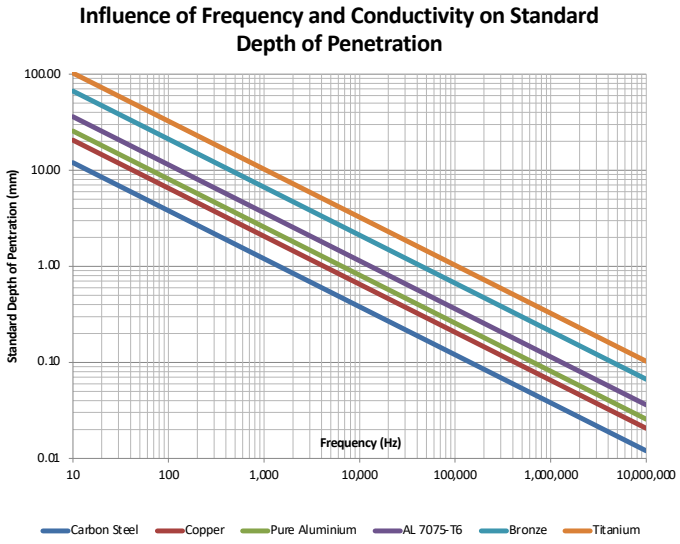
Comparison UT v EC v X-Ray



	Eddy Current (ET)	Ultrasonic (UT)	X-Ray
Principal Sensing	Conductivity	Impedance	Density
One sided	One sided	2 sided	
Morphology	Vertical	Horizontal	Volumetric

Eddy Current Physics



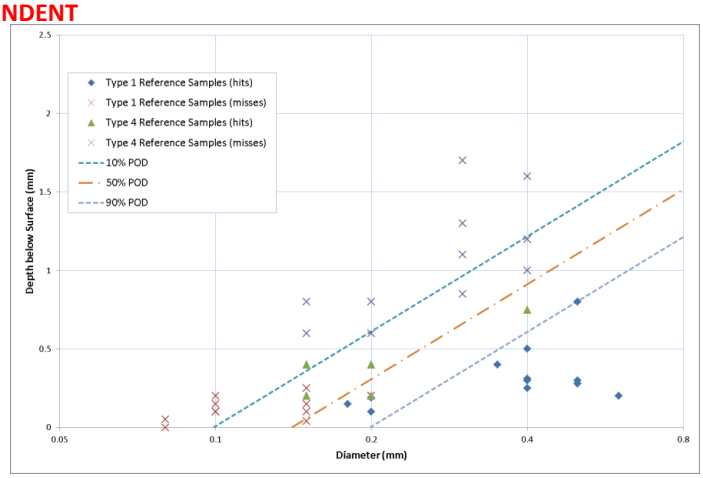
What is unique about Eddy Current?

- ✓ No issues with couplant or radiation
- ✓ Can inspect layer by layer or several layers at a time. A 200kHz test frequency on Inconel, Stainless and Titanium test to a depth of 1mm and at 2MHz 0.5mm
- ✓ More sensitive to injurious stress raisers e.g. cracks
- ✓ Easier to automate as instant on
- ✓ Rapid scanning up to $5ms^{-1}$
- ✓ Potential to assess residual stress

Problem with Powder bead Fusion but other methods (e.g. LMD and DED) are OK

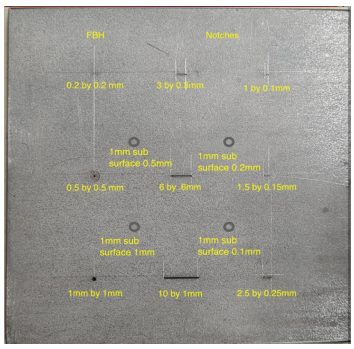
Performance Data (Intrapid) Eddy Current 2MHz

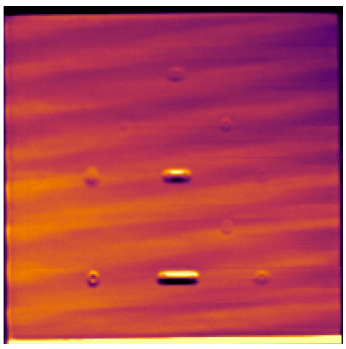
MATERIAL, EQUIPMENT, PROCEDURE, GEOMETRY AND FLAW MORPHOLOGY DEPENDENT



Scan with 2D Differential Probe developed but not used in final tests because of Residual Stress Focus

ECT modelling at TWI was used to asses ETher developed candidate probe solutions. Two novel 2d Eddy Current probes were developed.





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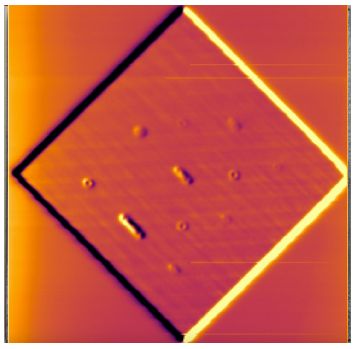

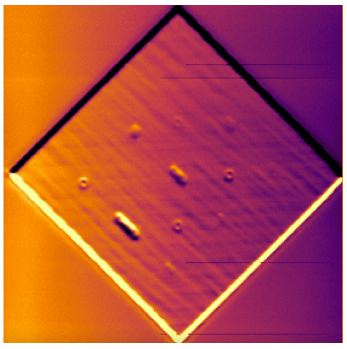

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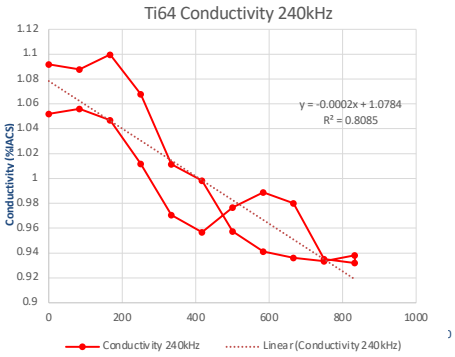
Residual Stress Measurement

Results showing Loading and unloading

Results look promising but the probe construction needs to be improved to make the responses more consistent,

The main issue with variability is assumed to be conductivity and temperature.

1 degree Centigrade gives a change in conductivity of the same order of the changes that are being observed.



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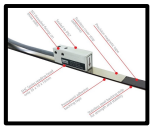
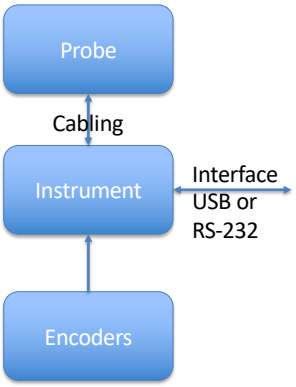
A System for on AM machine EC NDT

In order to make an automated Eddy Current NDT system what is needed is ;

- A probe - may need to be high temperature and also mounting/exchange must be considered
- Cabling – will need to be compatible with the environment
- Instrument – AMCheck or PhaseCheck
- Incremental Encoder Inputs – for C-Scan
- Interface to Machine control System





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What are the problems in adding Eddy Current NDT to a 3D Printer

Three principal problems;

- How do you attach the probe?
- How do we get encoder signals?
- How do can you Analyse the data?

Performance Verification/Calibration is another factor that also needs to be taken inot account.

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Mechanical and Electrical Interfacing System

HYBRID MANUFACTURING TECHNOLOGIES

In the EM-ReSt project Hybrid Manufacturing had already developed a solution to retrofit DED AM to an conventional CNC machine.

- The probe was built into a tool head.
- This approach gave mechanical and electrical interfacing system which enabled the coupling of the inspection probe heads independent of the laser metal additive system.
- Then the software was developed to control and synchronize input and output sensor data capture .

https://hybridmanutech.com/portfolio/ambit-inspection-heads-eddy/

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The probe problem

- Like on the EM-ReSt project the probe could be treated as a tool but this requires a mechanism and extensive modifications to the machine
- Alternatively an automatic retracting probe holder could be used (perhaps with air cooling). ETher ceramic tipped probes can operate at up to 200C.
- It is not necessary to scan every layer of a part as it is built, as eddy current testing has been demonstrated to test to 0.5 mm depth, so this could be every 2-4 layers,

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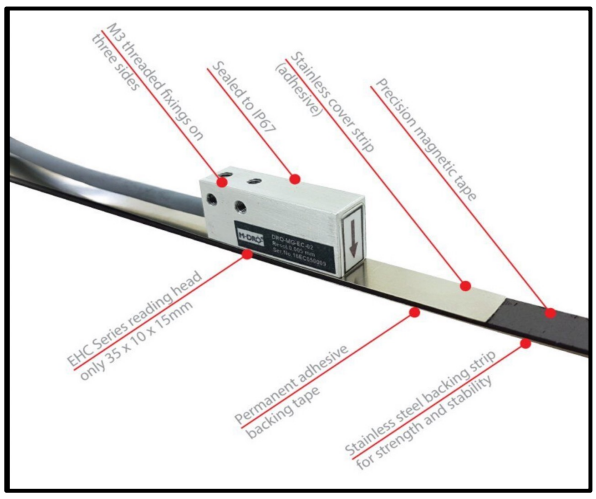
The Encoder Problem

Usually it is not possible to use the CNC machine encoders. Retrofitting an encoder system is relatively simple and low priced using a Compact Magnetic Tape Digital Readout Encoder.

Incremental linear magnetic encoder 5um resolution available up to 1450mm length



Data Analysis/Processing

Here one of three approaches could be used. It is also possible to integrate 2 or more of the below approaches.

- Alarm Based
- Machine Learning
- C-Scan

Or in fact two or more could be used in tandem.

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Alarm based

This is the traditional means of applying eddy current in automation NDT and coupled with accurate probe movement and test start enabled signals, careful use of alarm settings and filters can be extremely effective.

Advantages

Needs no encoders

Will fit easily into a manufacturer's existing QA system.

Disadvantages

Not image based

Binary approach to defects

No archival data recording (although system could return to a defect location if there were encoders)

Manual setup required by a NDT Technician

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Machine Learning

A machine learning system could be used to classify defects and if coupled with encoders then data could be presented showing defect location and flaw type. This has been shown to be 99% reliable.

Advantages

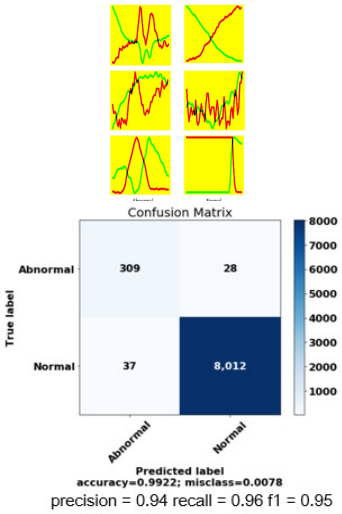
Does not require a skilled NDT Technician (although the system operation should be verified).

More information about defect types could be presented

ML could be used to construct an encoder less C-Scan

Disadvantages

Auditability of the ML Process



precision = 0.94 recall = 0.96 f1 = 0.95

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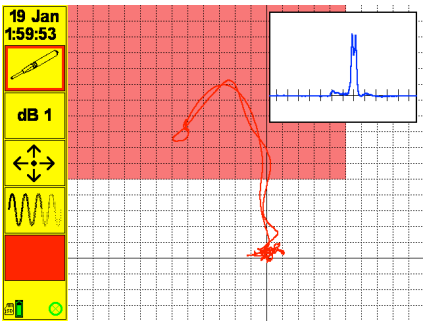

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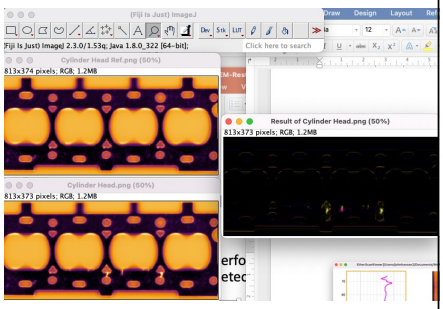
C-Scan

A C-scan image requires encoders but produces visual information.

- **Advantages**
- Visual
- Very Auditable
- **Disadvantages**
- Requires a NDT Technician
- Requires encoders



Further in the case of repetitive scans being done then by using image subtraction then anomalies can be readily flagged up.

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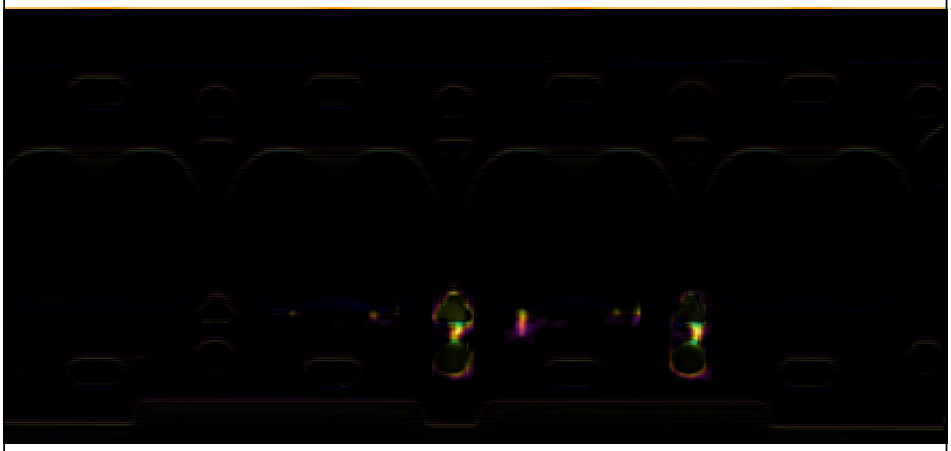
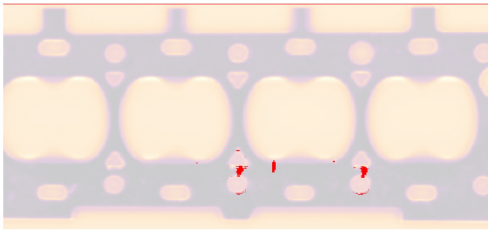
Cylinder head with defects Part 1

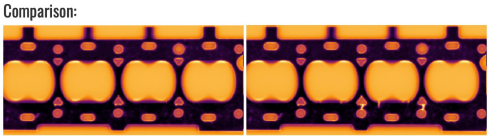


Cylinder head with defects Part 2

Result:



Comparison:



Options:

- Fuzz: 50%
- Highlight Color: red

https://online-image-comparison.com/result

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Any Questions

Contact john@ethernde.com