



THE MATERIALS JOINING EXPERTS



**NDE AND EDDY
CURRENT METHODS
FOR PIPELINE COATING
INSPECTION**

**NIST Workshop on
Advanced Coatings R&D
for Pipelines and
Related Facilities June 05**

**Evgueni Todorov, Ph.D.
Engineering and NDE**

PH. 614-688-5268, FAX 614-688-5001



THE MATERIALS JOINING EXPERTS

Contents

- NDE of coatings
 - General
 - Coating failures
 - Ultrasonics (UT)
 - Magnetic method
 - Infrared thermography
- Eddy current (EC) method
 - Definitions
 - Tasks
 - Typical probes and equipment
 - Examples of current procedures
- EC magnetic winding magnetometer (MWM)
 - General
 - Typical equipment and grids
 - Aluminum over carbon steel
 - Stainless steel over carbon steel
- EC computer modeling (ECCM)
 - Coating thinning at different frequencies
 - Substrate inspections
- Advantages and disadvantages of EC
- Conclusions and recommendations

EWI

THE MATERIALS JOINING EXPERTS

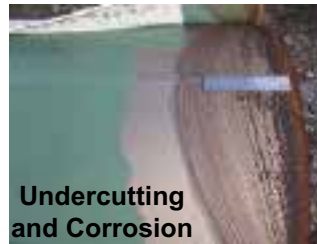
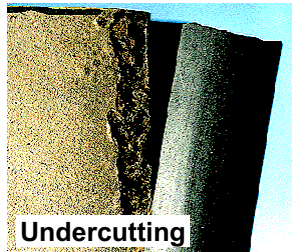
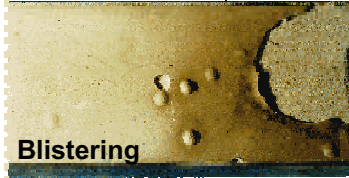
NDE of Coatings - General

- Most ASTM standards address the use of Eddy Current and Magnetic methods for thin coating thickness measurement (ASTM E 376, G12)
- Except visual inspection technique, few examples if any are available for characterization of thick coatings on the pipelines
- Typical tasks
 - Coating (or substrate) thickness measurement
 - Quality of coating (or substrate) material – degradation, porosity, voids, cracks
 - Adhesion of coating to the substrate – quality of bond, disbond areas, undercutting

EWI

THE MATERIALS JOINING EXPERTS

NDE of Coatings - Coating Failures



EWi

THE MATERIALS JOINING EXPERTS

NDE of Coatings - Ultrasonics (UT)

- General description and areas of application
 - Time-of-flight technique usually used for coating thickness measurements
 - Well established acoustically reflective interface between the coating and the substrate required
 - UT method C-Scan used for disbonds and voids detection and sizing
- Limitations
 - Organic or other highly attenuative coatings difficult or impossible to examine
 - If the interface is not acoustically reflective, the UT inspection is impossible
 - Small porosity or coating property variations that do not affect significantly the velocity of sound propagation are not detectable
 - In general, coating thickness has to be larger than 1-2 mm
 - Couplant is required
 - Multiple coating layers are difficult to evaluate

EWi

THE MATERIALS JOINING EXPERTS

NDE of Coatings - Magnetic Method

- General description and areas of application
 - Magnetic attraction or magnetic flux measurements usually used for coating thickness inspection
 - Ferromagnetic substrate or coating is required
 - Coating thickness may range from 0 to 2 mm
- Limitations
 - The substrate or coating has to be ferromagnetic
 - Coating properties such as porosity, degradation, and flaws are not measured
 - Disbond between the coating and the substrate cannot be detected with magnetic methods
 - The method is not used for multiple coating layers

EWI

THE MATERIALS JOINING EXPERTS

NDE of Coatings - Infrared Thermography

- General description and areas of application
 - Heat distribution in substrate-coating combination is studied under pulse or continuous heating
 - The method can potentially be used for evaluation of disbonds and coating degradation
- Limitations
 - Coating thickness may be difficult to assess
 - Thin metal coatings may be difficult to inspect

EWI

THE MATERIALS JOINING EXPERTS

Eddy Current (EC) - Definitions

LO - lift off

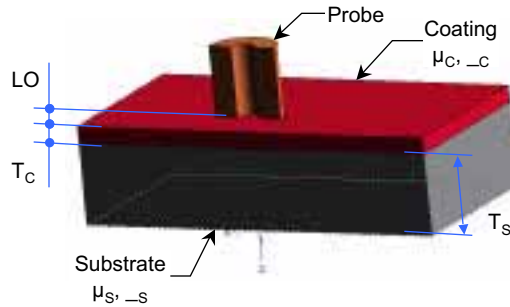
T_C - coating thickness

T_S - substrate thickness

f - current frequency

μ_{s, σ_s} - magnetic permeability and electrical conductivity of substrate

μ_{c, σ_c} - magnetic permeability and electrical conductivity of coating



RULES OF THUMB

To detect any coating changes

$$\frac{3}{\sqrt{\pi f \mu_c \sigma_c}} > T_C \quad \begin{aligned} \mu_c \sigma_c &> 1.5 \mu_s \sigma_s \\ \mu_s \sigma_s &> 1.5 \mu_c \sigma_c \end{aligned}$$

To eliminate substrate thickness changes on coating thickness measurements

$$\frac{3}{\sqrt{\pi f \mu_s \sigma_s}} < T_S$$

EWi

THE MATERIALS JOINING EXPERTS

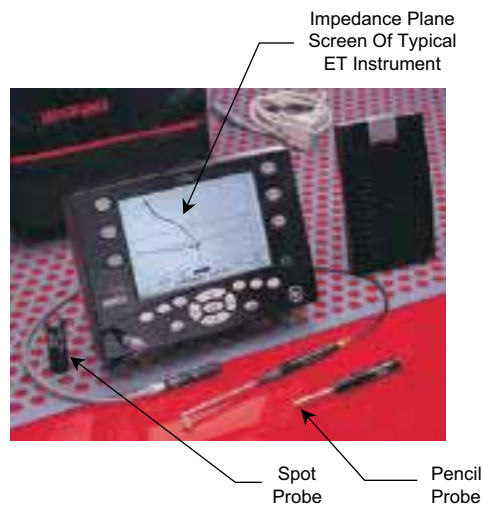
EC - Tasks

- Parameters to be measured
 - Coating (or substrate) thickness
 - Coating (or substrate) properties – e.g., degradation that affects μ_c and σ_c (μ_s and σ_s)
 - Coating (or substrate) cracks, corrosion, and other flaws
 - Coating-substrate combinations regarding EC
 - Metal coating on non-conductive and non-ferromagnetic substrate – metallic film on glass, ceramics or plastics
 - Non-ferromagnetic and non-conductive coating on metal non- or ferromagnetic substrate – paint, cement, rubber, other insulation organic coatings
- NOTE: Major case for pipelines
- Non-ferromagnetic and conductive coating on metal non- or ferromagnetic substrate – aluminum, copper, cadmium, or zinc on carbon steel, pure aluminum on aluminum alloy
 - Ferromagnetic and conductive coating on metal ferromagnetic substrate – cobalt or nickel on carbon steel

EWi

THE MATERIALS JOINING EXPERTS

EC - Typical Probes and Equipment



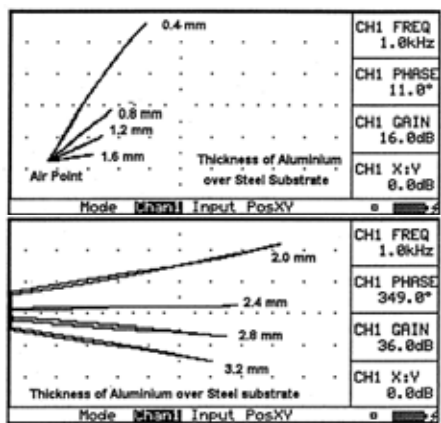
Pencil Probe

EWI

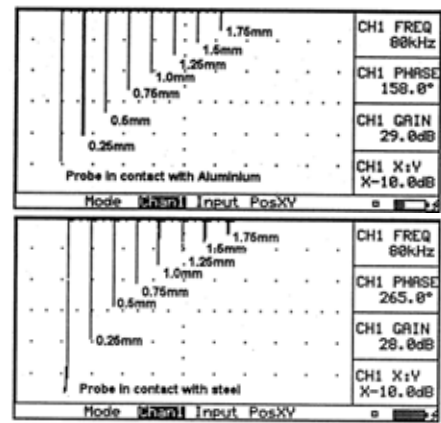
THE MATERIALS JOINING EXPERTS

EC - Examples of Current Procedures

Aluminum coating over carbon steel



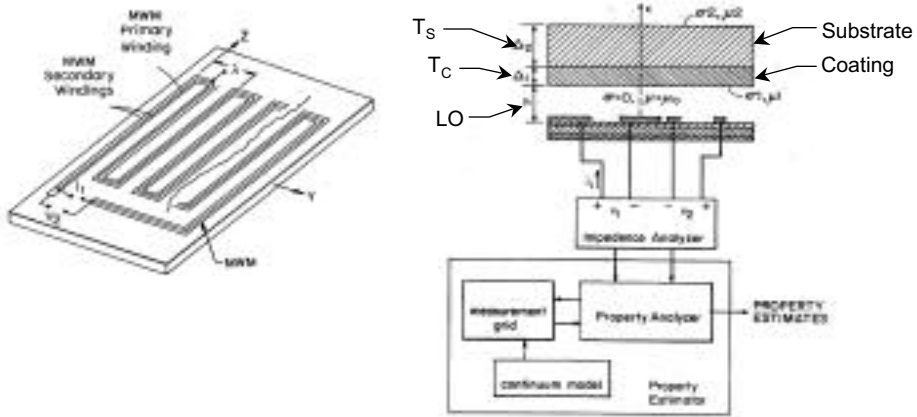
Paint coating over aluminum and carbon steel



EWI

THE MATERIALS JOINING EXPERTS

EC Magnetic Winding Magnetometer (MWM) - Principle



EWi

THE MATERIALS JOINING EXPERTS

MWM - Typical Equipment and Grids

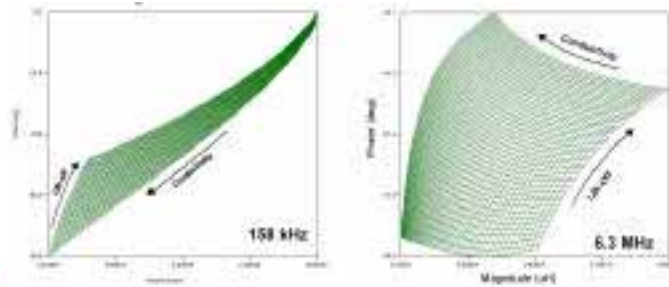


MWM Conformable Probe



MWM Instrument

Conductivity-Lift-Off Grids

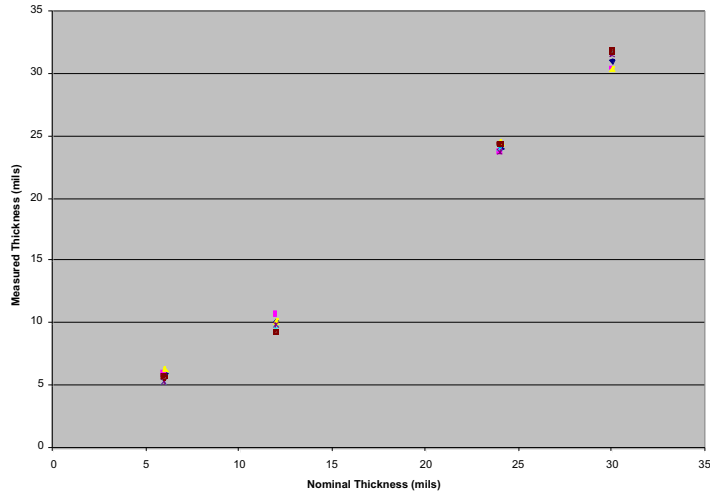


EWi

THE MATERIALS JOINING EXPERTS

MWM - Aluminum over Carbon Steel

Aluminum Coating Thickness Measurements (calibration using AL-TH-1, 24 mil coating)



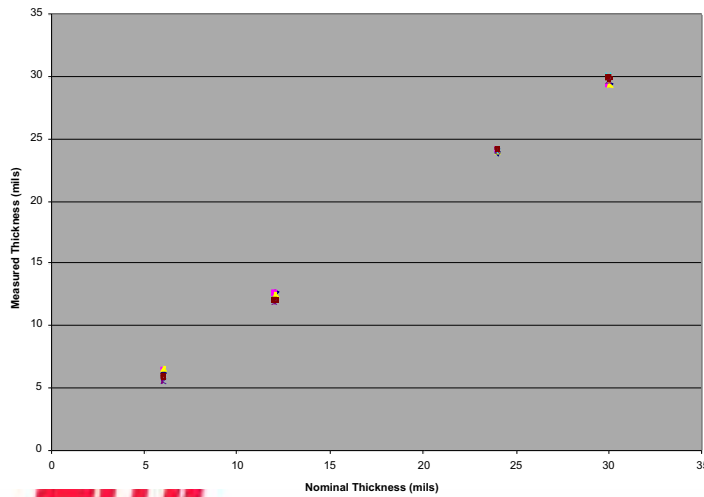
One set of 3 specimens measured at 2 locations



THE MATERIALS JOINING EXPERTS

MWM - Stainless Steel over Carbon Steel

Stainless Steel Coating Thickness Measurements (calibration using SS-TH-1, 24 mil coating)

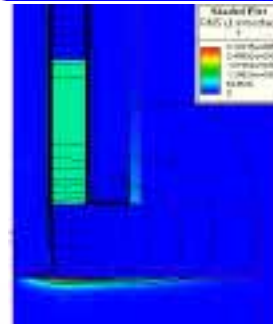
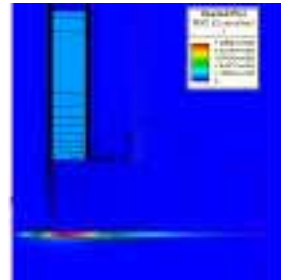
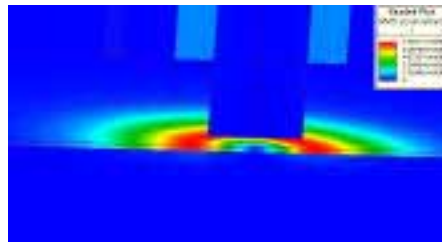


One set of 3 specimens measured at 2 locations



THE MATERIALS JOINING EXPERTS

EC Computer Modeling (ECCM)



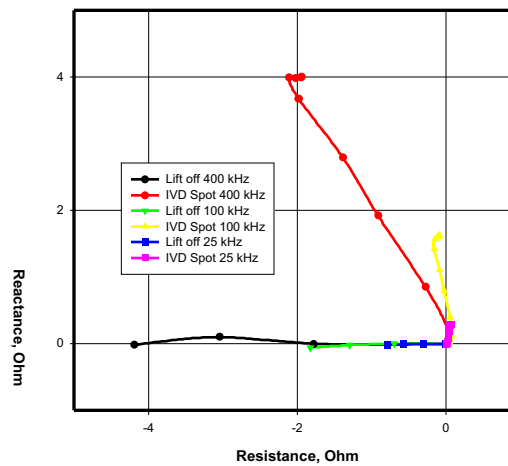
EWi

THE MATERIALS JOINING EXPERTS

ECCM - Coating Thinning at Different Frequencies

- Coating thickness and property (e.g., conductivity) variations can be assessed in advance

Simulation of Coating Thinning Signal
IVD Aluminum Coating Spot
Depth 0.0005 inch, Width 0.23 inch

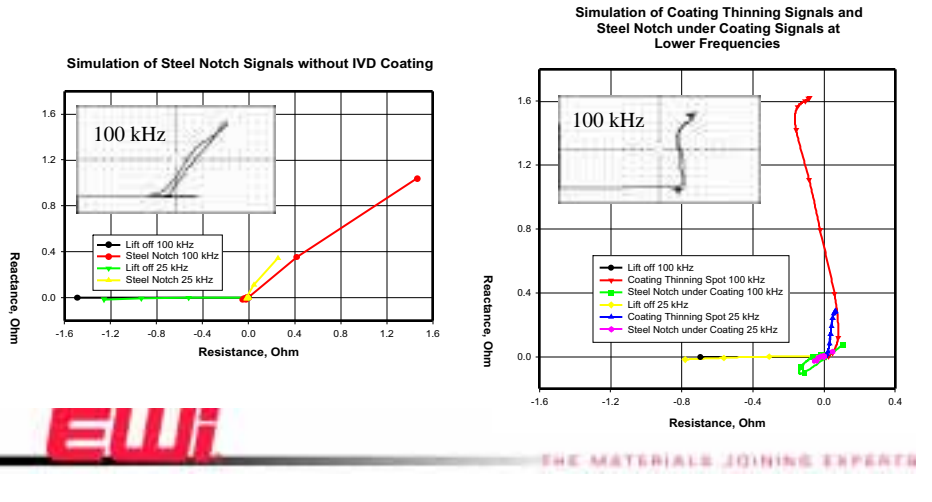


EWi

THE MATERIALS JOINING EXPERTS

ECCM - Substrate Inspections

Large cracks in the substrate may be completely masked by coating thickness variations



Advantages and Disadvantages of EC

- Advantages
 - Does not require couplant
 - Very accurate for thin layers
 - Capable of examining multiple layers when aided with modeling and advanced technologies
 - Fast and easy to set up for field inspections
 - One instrument can perform thickness and flaw inspections on both coating and substrate
 - Change of coating properties (degradation, porosity, corrosion) that affect coating conductivity and/or magnetic permeability can be detected
- Disadvantages
 - Disbond between coating and substrate is difficult or impossible to detect
 - Depending on the application, one or several layers have to be conductive and/or ferromagnetic
 - Only thickness (to certain range) is measured if the coating is non-conductive and non-ferromagnetic (paint, organic insulation, others)

EWi

THE MATERIALS JOINING EXPERTS

Conclusions and Recommendations

- New technologies and modeling approach allow development of new techniques for problems that have been outside of the scope of current procedures
- Computer modeling especially for complex cases brings the following benefits:
 - Significantly reduced time for development and validation of procedures used for inspection of complex geometry structures where NDT technique performance is unknown
 - Significant cost benefits due to elimination and reduction of experimental specimens and mock-ups needed for technique and procedure validation
 - Increased inspection reliability and repeatability
 - Fast interpretation of field NDE data and reduction of unnecessary repairs
 - Quick customer support turnaround
- Several NDE techniques may be required to fully characterize the coating-substrate structure on the pipelines

EWI

THE MATERIALS JOINING EXPERTS