Detecting Compressive Residual Stress in Carbon Steel Specimens of Flat Geometries Using the Remote-Field Eddy Current Technique

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Introduction
Remote Field Eddy Current Technique
Recent Extension of RFEC Techniques for the Inspection of Objects with Flat Geometries
Probes & Specimens for Residual Stress Detection
Scan Modes
Detected Signals versus Force, Mode 2
Detected Signals versus Frequencies, Mode 1
Detected Signals from the 0.5” Specimen, Mode 2
Summary
INTRODUCTION

• Detecting of residual stress in infrastructure is of great concern.

• Existing EC techniques are not capable of detecting deeply hidden flaws.

• Recent developments in RFEC Technique show promise.

• In this presentation:
  
  Introduction of new developments in the application of the RFEC technique

  Sensitivity of the RFEC System to Residual Stress.
Remote Field Eddy Current Technique

**Phenomenon:**

Signals received by pick-up coil are closely related to the wall condition: thickness, conductivity, and permeability.

**Underlying Physics:**

1. Direct energy coupling is restricted by EC in the wall.
2. Pick-up coil signal, $\Phi_{RF}$, is dominated by the energy diffusing along the indirect coupling path that traverses the wall twice.
3. Phase of $\Phi_{RF}$ has a linear relation with the wall thickness.
Recent Extension of RFEC in Inspection of Objects of Flat Geometries

Latest test data* show that the system can detect:

1. aluminum material discontinuities 1.0” below the inspection surface;
2. 12.7 mm x 12.7 mm x 0.15mm corrosion thinning, 9.5 mm below the surface;
3. a 12.7 mm x 0.9 mm x 0.25 mm saw-cut 6.7 mm below the surface;
4. a 0.78 mm long second layer fastener hole fatigue crack 11.3 mm below surface

* Additional information is available upon request from the presenter, or from Professor Y. Sun via email: suny@iastate.edu
Probes & Specimens for Residual Stress Detection

**Two specimens made of carbon steel:**
1. 16” Long x 4” wide x 0.25” thick
2. 12.5” long x 2.5” wide x 0.5” thick

**RFEC Probe RF-4mm**

Excitation Coil  Pick-up Coil

Footprint: 55mm(L) x 22 mm(W) x 22 mm (H)
Probes & Specimens for Residual Stress Detection

Photograph of the 0.5” Thick Specimen

Specimen with milled pits of same dimensions

Specimen with pressed indents

50 klb Indent

30klb Indent
Two Scan Modes

Mode 1:
Axially Oriented Probe
Axial Scan

Mode 2:
Vertically Oriented Probe
Axial Scan
Detected Signals versus Force Values, Mode 2

F = 100 Hz, Vertical Oriented Probe, 0.25” Specimens
Axial A-Scan with Probe Center Passing Over Indent Center

Mode 2

Indent
Detected Signals versus Force Values, Mode 2

F = 100 Hz, Vertical Oriented Probe, 0.25” Specimens
Axial A-Scan with Probe Center Passing Over Indent Center

Signal Obtained from A Metal Loss Pit Simulating 50 klb indent
Detected Signals versus Force Values, Mode 2

F = 1,000 Hz, Vertical Oriented Probe, 0.25” Specimens
Axial A-Scan with Probe Center Passing Over Indent Center

Mode 2

Indent
Detected Signals versus Force Values, Mode 2

F = 1,000 Hz, Vertical Oriented Probe, 0.25” Specimens
Axial A-Scan with Probe Center Passing Over Indent Center

Signal Obtained from A Metal Loss Pit
Simulating 50 klb indent

Mode 2

Indent
Detected Signals versus Force Values, Mode 2

SOME OBSERVATIONS

1. At $f = 100$ Hz with vertical oriented probe, indent signal increases monotonically with increase in force.

2. At $f = 1,000$ Hz with vertical oriented probe, indent signal increases in general with the increase in force, but with a few exceptions. Additional experimental work is needed.

3. In most cases, the complex trajectory of a signal is a single loop. However, double-loop trajectories are also obtained. Additional experimental work is needed.

4. No signals can be detected from metal loss pits
Detected Signals versus Frequencies, Mode 1
F = 100 Hz, 0.25” Specimen, 55kIb Indent
Axial Scan with Axially Oriented Probe
Detected Signals versus Frequencies, Mode 1

F = 100 Hz, 0.25" Specimen, 55kib Indent
Axial Scan with Axially Oriented Probe

Mode 1

1st Signal Zone

Two signal zones with different phase angles are observed –
The ratios of Imaginary/Real are different in the two zones.

2nd Signal Zone
Detected Signals versus Frequencies, Mode 1

F = 100 Hz, 0.25” Specimen, 55klb Indent
Axial Scan with Axially Oriented Probe

At 100 Hz - Signal peak in 1st zone is greater than that in 2nd zone
Detected Signals versus Frequencies, Mode 1

F = 400 Hz, 0.25” Specimen, 55klb Indent
Axial Scan with Axially Oriented Probe
Detected Signals versus Frequencies, Mode 1

F = 400 Hz, 0.25” Specimen, 55kib Indent
Axial Scan with Axially Oriented Probe

Mode 1

At = 400 Hz - Difference in signal peaks of the two zones is less
The peak of the 1st zone signal has spread to the left
Detected Signals versus Frequencies, Mode 1
F = 1,600 Hz, 0.25” Specimen, 55kIlb Indent
Axial Scan with Axially Oriented Probe

Mode 1

Real

Imaginary

1st Signal Zone

2nd Signal Zone
Detected Signals versus Frequencies, Mode 1

F = 1,600 Hz, 0.25” Specimen, 55klb Indent
Axial Scan with Axially Oriented Probe

Mode 1

At = 1,600 Hz
Signal peak in 1\textsuperscript{st} zone is much less than that in 2\textsuperscript{nd} zone
The peak of the 1\textsuperscript{st} zone signal has moved to the left a lot
The 2\textsuperscript{nd} zone has spread a little wider
Detected Signals versus Frequencies, Mode 1

OBSERVATIONS

1. Two signal footprints are observed for each indent. Differences in their phase angles are observed. This corresponds to the double-loops observed earlier.

2. Relatively, the signal magnitude in the first zone decreases, while the signal in the second zone increases with increase in frequency.

3. The peak location of the first zone signal may vary with frequency. Therefore, the signal peak value may not be captured by a single A-scan.

4. At f=1,600 Hz the 1st zone signal becomes much smaller than that in the 2nd zone.
Detected Signals from the 0.5” Specimen, Mode 2

F = 500 Hz, 50klb Indent, Imaginary Component
(Lift-off was set on real component axis)
Detected Signals from the 0.5” Specimen, Mode 2
F = 500 Hz, 50klb Indent, Signal Magnitude
(Lift-off was set on real component axis)
Detected Signals from the 0.5” Specimen, Mode 2
F = 500 Hz, 50klb Indent, Signal Magnitude
(Lift-off was set on real component axis)

Mode 2

**1st Signal Zone**

**2nd Signal Zone**
Summary

1. Compressive residual stress in carbon steel specimens can be detected using the RFEC system for flat geometry objects.
2. The signal footprint obtained from a circular indent is elliptical in shape with the large axis along the probe axis.
3. Test results obtained to date show:
   - The detected signal magnitude increases with increase in force applied to the specimen.
   - Two distinct regions are observed in the signal footprint from a single indent. The signals in the two zones have different phase angles.
   - The relative relation between the signal peaks of the two zone varies with frequency. Increasing the frequency causes the signal peak in the first zone to decrease, while the signal peak in the second zone increases.
4. The underlying physics associated with the process requires careful study.
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