ET

ELECTROMAGNETIC TESTING TOPICAL OUTLINES

Alternating Current Field Measurement Testing Level I Topical Outline

Theory Course

1.0 Introduction to Electromagnetic Testing (ET)
- 1.1 Brief history of testing
- 1.2 Basic principles of NDT

2.0 Electromagnetic Theory
- 2.1 Eddy current theory
  - 2.1.1 Generation of eddy currents by means of an alternating current (AC) field
  - 2.1.2 Effects of fields created by eddy currents
  - 2.1.3 Properties of eddy currents
    - 2.1.3.1 Travel in circular direction
    - 2.1.3.2 Eddy current distribution
    - 2.1.3.3 Effects of liftoff and geometry
    - 2.1.3.4 Relationship of magnetic field in relation to a current in a coil
    - 2.1.3.5 Effects of permeability variations in magnetic materials
    - 2.1.3.6 Effect of discontinuities
    - 2.1.3.7 Relationship between frequency and depth of penetration
    - 2.1.3.8 Standard depths of penetration
- 2.2 Flux leakage theory
  - 2.2.1 Terminology and units
  - 2.2.2 Principles of magnetization
    - 2.2.2.1 *B-H* curve
    - 2.2.2.2 Magnetic properties
    - 2.2.2.3 Magnetic fields
    - 2.2.2.4 Magnetic permeability
    - 2.2.2.5 Factors affecting magnetic permeability
- 2.3 Basic electrical theory
  - 2.3.1 Basic units of electrical measurement
  - 2.3.2 Direct current circuits
  - 2.3.3 Ohm's law
  - 2.3.4 Faraday's law
  - 2.3.5 Resistance
  - 2.3.6 Inductance
  - 2.3.7 Magnetic effect of electrical currents

Technique Course

1.0 Alternating Current Field Measurement (ACFM) Theory
- 1.1 Production of uniform fields
- 1.2 Current flow, B_x, B_z, and B_y relationships
- 1.3 Relationship of the B_x, B_z, and butterfly plots
- 1.4 Other sources that influence the signals

2.0 Types of Probes
- 2.1 Coil arrangements
  - 2.1.1 Primary induction coil
  - 2.1.2 B_x and B_y sensor coils
- 2.2 Coil factors (liftoff)
- 2.3 Theory of operation
- 2.4 Applications
- 2.5 Limitations
- 2.6 Probe markings

3.0 Probe Software
- 3.1 Probe software versions and compatibility
- 3.2 Manufacturers' sensitivity settings
  - 3.2.1 Gain
  - 3.2.2 Scalings
  - 3.2.3 Relationship between gain and current settings
- 3.3 Sensitivity checks

4.0 Factors Affecting the Choice of Probes
- 4.1 Type of part to be inspected
- 4.2 Type of discontinuity to be inspected
- 4.3 Speed of testing required
- 4.4 Probable location of discontinuity

5.0 Types of Hardware and Operating Software Applications
- 5.1 Choice of systems for specific applications
- 5.2 Choice of software for specific applications
  - 5.2.1 Depth and length sizing capabilities
  - 5.2.2 Probe resolution
  - 5.2.3 Coating thickness

6.0 Scanning for Detection
- 6.1 Initial setup
- 6.2 Setting position indicators
- 6.3 Probe orientation
- 6.4 Scanning speed
- 6.5 Scanning pattern for tubulars and pipes
- 6.6 Scanning pattern for linear sections
- 6.7 Scanning for transverse cracks

7.0 Signal Interpretation
- 7.1 Review of display format
- 7.2 Detection and examination procedure
- 7.3 Crack signals – linear cracks, angled cracks, line contacts and multiple cracks, transverse cracks
- 7.4 Other signal sources – liftoff, geometry, materials, magnetism, edges, and corners

Alternating Current Field Measurement Testing Level II Topical Outline

Principles Course

1.0 Review of Electromagnetic Theory
- 1.1 Eddy current theory
- 1.2 ACFM theory
- 1.3 Types of ACFM sensing probes

2.0 Factors that Affect Depth of Penetration
- 2.1 Conductivity
- 2.2 Permeability
- 2.3 Frequency
- 2.4 Coil size

3.0 Factors that Affect ACFM
- 3.1 Residual fields
- 3.2 Defect geometry
- 3.3 Defect location – scanning pattern for attachments, corners, and ratholes
- 3.4 Defect orientation
- 3.5 Distance between adjacent defects

Techniques and Applications Course

1.0 Software Commands
- 1.1 Probe file production
  - 1.1.1 Selection of gain and frequency settings for specific applications
  - 1.1.2 Selection of current for specific applications
  - 1.1.3 Selections of sensitivity settings and scalings for specific applications
- 1.2 Standardization settings
  - 1.2.1 Alarm settings
  - 1.2.2 Butterfly plot scalings
- 1.3 Adjustment of communication rates

2.0 User Standards and Operating Procedures
- 2.1 Explanation of standards applicable to ACFM
- 2.2 Explanation of operating procedures applicable to ACFM

Eddy Current Testing Level I Topical Outline

Theory Course

1.0 Introduction to Eddy Current Testing
- 1.1 Historical and developmental process
  - 1.1.1 Founding fathers: Arago, Lenz, Faraday, and Maxwell
  - 1.1.2 Advances in electronics
- 1.2 Basic physics and controlling principles
  - 1.2.1 Varying magnetic fields
  - 1.2.2 Electromagnetic induction
  - 1.2.3 Primary and secondary force relationships

2.0 Electromagnetic Theory
- 2.1 Eddy current theory
  - 2.1.1 Generation of eddy currents by means of an AC field
  - 2.1.2 Effect of fields created by eddy currents (impedance changes)
  - 2.1.3 Effect of change of impedance on instrumentation
  - 2.1.4 Properties of eddy current
    - 2.1.4.1 Travel in circular direction
    - 2.1.4.2 Strongest on surface of test material
    - 2.1.4.3 Zero value at center of solid conductor placed in an alternating magnetic field
    - 2.1.4.4 Strength, time relationship, and orientation as functions of test-system parameters and test-part characteristics
    - 2.1.4.5 Small magnitude of current flow
    - 2.1.4.6 Relationships of frequency and phase
    - 2.1.4.7 Electrical effects, conductivity of materials
    - 2.1.4.8 Magnetic effects, permeability of materials
    - 2.1.4.9 Geometrical effects

3.0 Lab Demonstration
- 3.1 Generation of Z-curves with conductivity samples
- 3.2 Generation of liftoff curves

Basic Technique Course

1.0 Types of Eddy Current Sensing Elements
- 1.1 Probes
  - 1.1.1 Types of arrangements
    - 1.1.1.1 Probe coils
    - 1.1.1.2 Encircling coils
    - 1.1.1.3 Inside coils
  - 1.1.2 Modes of operation
    - 1.1.2.1 Absolute
    - 1.1.2.2 Differential
    - 1.1.2.3 Hybrids
  - 1.1.3 Theory of operation
  - 1.1.4 Hall effect sensors
    - 1.1.4.1 Theory of operation
    - 1.1.4.2 Differences between coil and Hall element systems

1.1.5 Applications
1.1.5.1 Measurement of material properties
1.1.5.2 Flaw detection
1.1.5.3 Geometrical features
1.1.6 Advantages
1.1.7 Limitations
1.2 Factors affecting choice of sensing elements
1.2.1 Type of part to be inspected
1.2.2 Type of discontinuity to be detected
1.2.3 Speed of testing required
1.2.4 Amount of testing (percentage) required
1.2.5 Probable location of discontinuity

2.0 Selection of Inspection Parameters
2.1 Frequency
2.2 Coil drive – current/voltage
2.3 Hall effect element drive – current/voltage
2.4 Channel gain
2.5 Display sensitivity selections
2.6 Standardization
2.7 Filtering
2.8 Thresholds

3.0 Readout Mechanisms
3.1 Calibrated or uncalibrated meters
3.2 Impedance plane displays
3.2.1 Analog
3.2.2 Digital
3.3 Data recording systems
3.4 Alarms, lights, etc.
3.5 Numerical readouts
3.6 Marking systems
3.7 Sorting gates and tables
3.8 Cutoff saw or shears
3.9 Automation and feedback

4.0 Lab Demonstration
4.1 Demo filter effects on rotating reference standards
4.2 Demo liftoff effects
4.3 Demo frequency effects
4.4 Demo rotational and forward speed effects
4.5 Generate a Z-curve with conductivity standards

Eddy Current Testing Level II Topical Outline

Principles Course

1.0 Review of Electromagnetic Theory
1.1 Eddy current theory
1.2 Types of eddy current sensing probes

2.0 Factors that Affect Coil Impedance
2.1 Test part
2.1.1 Conductivity
2.1.2 Permeability
2.1.3 Mass
2.1.4 Homogeneity
2.2 Test system
2.2.1 Frequency
2.2.2 Coupling
2.2.3 Field strength
2.2.4 Test coil and shape
2.2.5 Hall effect elements

3.0 Signal-to-Noise Ratio
3.1 Definition
3.2 Relationship to eddy current testing
3.3 Methods of improving signal-to-noise ratio (SNR)

4.0 Selection of Test Frequency
4.1 Relationship of frequency to type of test
4.2 Considerations affecting choice of test
4.2.1 SNR
4.2.2 Causes of noise
4.2.3 Methods to reduce noise
4.2.3.1 DC saturation
4.2.3.2 Shielding
4.2.3.3 Grounding
4.2.4 Phase discrimination
4.2.5 Response speed
4.2.6 Skin effect

5.0 Coupling
5.1 Fill factor
5.2 Liftoff

6.0 Field Strength and its Selection
6.1 Permeability changes
6.2 Saturation
6.3 Effect of AC field strength on eddy current testing

7.0 Instrument Design Considerations
7.1 Amplification
7.2 Phase detection
7.3 Differentiation of filtering

Techniques and Applications Course

1.0 User Standards and Operating Procedures
1.1 Explanation of standards and specifications used in eddy current testing

2.0 Inspection System Output
2.1 Accept/reject criteria
2.1.1 Sorting, go/no-go
2.2 Signal classification processes
2.2.1 Discontinuity
2.2.2 Flaw
2.3 Detection of signals of interest
2.3.1 Near surface
2.3.2 Far surface
2.4 Flaw-sizing techniques
2.4.1 Phase to depth
2.4.2 Volts to depth
2.5 Calculation of flaw frequency

- 2.6 Sorting for properties related to conductivity
- 2.7 Thickness evaluation
- 2.8 Measurement of ferromagnetic properties
  - 2.8.1 Comparative circuits

Remote Field Testing Level I Topical Outline

Theory Course

1.0 Introduction to Remote Field Testing (RFT)
- 1.1 Historical and developmental process
  - 1.1.1 Founding fathers: McLean, Schmidt, Atherton, and Lord
  - 1.1.2 The computer age and its effect on the advancement of RFT
- 1.2 Basic physics and controlling principles
  - 1.2.1 Varying magnetic fields
  - 1.2.2 Electromagnetic induction
  - 1.2.3 Primary and secondary field relationships

2.0 Electromagnetic Theory
- 2.1 Generation of eddy currents in conductors
- 2.2 Eddy current propagation and decay, standard depth of penetration
- 2.3 Near field, transition, and remote field zones
- 2.4 Properties of remote field eddy currents
  - 2.4.1 Through-transmission nature
  - 2.4.2 Magnetic flux is predominant energy
  - 2.4.3 The ferrous tube as a waveguide
  - 2.4.4 Strength of field in three zones
  - 2.4.5 External field is source of energy in remote field
  - 2.4.6 Factors affecting phase lag and amplitude
  - 2.4.7 Geometric factors – fill factor, external support plates, tube sheets
  - 2.4.8 Speed of test, relationship to thickness, frequency, conductivity, and permeability
  - 2.4.9 Effect of deposits – magnetite, copper, calcium
  - 2.4.10 RFT in nonferrous tubes

Basic Technique Course

1.0 Types of Remote Field Sensing Elements
- 1.1 Probes
  - 1.1.1 Types of arrangements
    - 1.1.1.1 Absolute bobbin coils
    - 1.1.1.2 Differential bobbin coils
    - 1.1.1.3 Arrays
  - 1.1.2 Modes of operation
    - 1.1.2.1 RFT voltage plane and reference curve
    - 1.1.2.2 X-Y voltage plane
    - 1.1.2.3 Chart recordings
  - 1.1.3 Theory of operation
  - 1.1.4 Applications
    - 1.1.4.1 Heat exchanger and boiler tubes
    - 1.1.4.2 Pipes and pipelines
    - 1.1.4.3 External and through-transmission probes
  - 1.1.5 Advantages
    - 1.1.5.1 Equal sensitivity to internal and external flaws
    - 1.1.5.2 Easy to understand – increasing depth of flaw signals rotate CCW
  - 1.1.6 Limitations
    - 1.1.6.1 Speed
    - 1.1.6.2 Difficult to differentiate internal versus external flaws
    - 1.1.6.3 Small signals from small-volume flaws
    - 1.1.6.4 Finned tubes
- 1.2 Factors affecting choice of probe type
  - 1.2.1 Differential for small-volume flaws (e.g., pits)
  - 1.2.2 Absolute for large-area defects (e.g., steam erosion, fretting)
  - 1.2.3 Test (probe travel) speed
  - 1.2.4 Single versus dual exciters and areas of reduced sensitivity
  - 1.2.5 Bobbin coils and solid-state sensors
  - 1.2.6 Finned tubes

2.0 Selection of Inspection Parameters
- 2.1 Frequency
- 2.2 Coil drive – current/voltage
- 2.3 Pre-amp gain
- 2.4 Display gain
- 2.5 Standardization

3.0 Readout Mechanisms
- 3.1 Display types
  - 3.1.1 RFT voltage plane displays
  - 3.1.2 Voltage vector displays
- 3.2 RFT reference curve
- 3.3 Chart recordings
- 3.4 Odometers
- 3.5 Storing and recalling data on computers

Principles Course

1.0 Review of Electromagnetic Theory
- 1.1 RFT theory
- 1.2 Types of RFT sensing probes

2.0 Factors that Affect Coil Impedance
- 2.1 Test part
  - 2.1.1 Conductivity
  - 2.1.2 Permeability
  - 2.1.3 Mass
  - 2.1.4 Homogeneity
- 2.2 Test system
  - 2.2.1 Frequency
  - 2.2.2 Coupling (fill factor)
  - 2.2.3 Field strength (drive volts, frequency)
  - 2.2.4 Coil shapes

3.0 Signal-to-Noise Ratio
- 3.1 Definition
- 3.2 Relationship to RFT
- 3.3 Methods of improving SNR
  - 3.3.1 Speed
  - 3.3.2 Fill factor
  - 3.3.3 Frequency
  - 3.3.4 Filters
  - 3.3.5 Drive
  - 3.3.6 Shielding
  - 3.3.7 Grounding (3.3.6 and 3.3.7 also apply to other methods)

4.0 Selection of Test Frequency
- 4.1 Relationship of frequency to depth of penetration
- 4.2 Relationship of frequency to resolution
- 4.3 Dual-frequency operation
- 4.4 Beat frequencies
- 4.5 Optimum frequency

5.0 Coupling
- 5.1 Fill factor
- 5.2 Importance of centralizing the probe

6.0 Field Strength
- 6.1 Probe drive and penetration
- 6.2 Effect of increasing thickness, conductivity, or permeability
- 6.3 Position of receive coils versus field strength

7.0 Instrument Design Considerations
- 7.1 Amplification
- 7.2 Phase and amplitude detection (lock-in amplifier)
- 7.3 Differentiation and filtering

Remote Field Testing Level II Topical Outline

Techniques and Applications Course

1.0 Equipment
- 1.1 Probes
  - 1.1.1 Absolute bobbin coils
  - 1.1.2 Differential bobbin coils
  - 1.1.3 Arrays
  - 1.1.4 Dual exciter or dual detector probes
  - 1.1.5 Solid-state sensors
  - 1.1.6 External probes
  - 1.1.7 Effect of fill factor
  - 1.1.8 Centralizing the probe
  - 1.1.9 Quality of the "ride"
  - 1.1.10 Cable length considerations
  - 1.1.11 Preamplifiers – internal and external
- 1.2 Instruments
  - 1.2.1 Measuring phase and amplitude
  - 1.2.2 Displays – RFT, voltage plane, impedance plane differences
  - 1.2.3 Chart recordings
  - 1.2.4 Storing, retrieving, archiving data
  - 1.2.5 Standardization frequency
- 1.3 Reference standards
  - 1.3.1 Material
  - 1.3.2 Thickness
  - 1.3.3 Size
  - 1.3.4 Heat treatment
  - 1.3.5 Simulated defects
  - 1.3.6 ASTM E2096
  - 1.3.7 How often to standardize

2.0 Techniques
- 2.1 Factors affecting signals
  - 2.1.1 Probe speed/smoothness of travel
  - 2.1.2 Depth, width, and length of flaw versus probe footprint
  - 2.1.3 Probe drive, pre-amp gain, view gain, filters
  - 2.1.4 Position of flaw versus other objects (e.g., support plates)
  - 2.1.5 Fill factor
  - 2.1.6 SNR
  - 2.1.7 Thickness, conductivity, and permeability of the tube
  - 2.1.8 Correct display of the signal
- 2.2 Selection of test frequencies
  - 2.2.1 Single or dual or multifrequency
  - 2.2.2 Sharing the time slice
  - 2.2.3 Number of readings per cycle
  - 2.2.4 Beat frequencies, harmonics, and base frequencies
  - 2.2.5 Optimum frequency
  - 2.2.6 Saturating the input amplifier (large-volume defects)
  - 2.2.7 Small-volume defects – optimizing the settings to detect

3.0 Applications
- 3.1 Tubulars using internal probes
  - 3.1.1 Heat exchanger tubes
  - 3.1.2 Boiler tubes
  - 3.1.3 Pipes
  - 3.1.4 Pipelines
  - 3.1.5 Furnace tubes
- 3.2 Tubulars using external probes
  - 3.2.1 Boiler tubes
  - 3.2.2 Process pipes
  - 3.2.3 Pipelines
  - 3.2.4 Structural pipes
- 3.3 Other applications
  - 3.3.1 Flat plate
  - 3.3.2 Finned tubes
  - 3.3.3 Hydrogen furnace tubes
  - 3.3.4 Nonferrous tubes and pipes
  - 3.3.5 Cast-iron water mains
  - 3.3.6 Oil well casings

4.0 Inspection System Output
- 4.1 Accept/reject criteria
  - 4.1.1 Customer specified or code specified
- 4.2 Signal classification processes
  - 4.2.1 Discontinuity
  - 4.2.2 Flaw
- 4.3 Detection of signals of interest
  - 4.3.1 Near/under support plates and tubesheets
  - 4.3.2 Flaws in the free span
  - 4.3.3 Internal and external flaws
  - 4.3.4 Recognition of signals from nonflaws
- 4.4 Signal recognition, data analysis, and flaw-sizing techniques
  - 4.4.1 Understanding the RFT reference curve and using it for flaw sizing
  - 4.4.2 Using phase angle to calculate flaw depth on the X-Y display
  - 4.4.3 Coil footprint considerations

Electromagnetic Testing Level III Topical Outline

Eddy Current Testing

1.0 Principles/Theory
- 1.1 Eddy current theory
  - 1.1.1 Generation of eddy currents
  - 1.1.2 Effect of fields created by eddy currents (impedance changes)
  - 1.1.3 Properties of eddy currents
    - 1.1.3.1 Travel mode
    - 1.1.3.2 Depth of penetration
    - 1.1.3.3 Effects of test-part characteristics – conductivity and permeability
    - 1.1.3.4 Current flow
    - 1.1.3.5 Frequency and phase
    - 1.1.3.6 Effects of permeability variations – noise
    - 1.1.3.7 Effects of discontinuity orientation

2.0 Equipment/Materials
- 2.1 Probes – general
  - 2.1.1 Advantages/limitations
- 2.2 Through, encircling, or annular coils and Hall effect elements
  - 2.2.1 Advantages/limitations/differences
- 2.3 Factors affecting choice of sensing elements
  - 2.3.1 Type of part to be inspected
  - 2.3.2 Type of discontinuity to be detected
  - 2.3.3 Speed of testing required
  - 2.3.4 Amount of testing required
  - 2.3.5 Probable location of discontinuity
  - 2.3.6 Applications other than discontinuity detection
- 2.4 Readout selection
  - 2.4.1 Meter
  - 2.4.2 Oscilloscope, X-Y, and other displays
  - 2.4.3 Alarm, lights, etc.
  - 2.4.4 Strip-chart recorder
- 2.5 Instrument design considerations
  - 2.5.1 Amplification
  - 2.5.2 Phase detection
  - 2.5.3 Differentiation or filtering
  - 2.5.4 Thresholds, box gates, etc.

3.0 Techniques/Standardization
- 3.1 Factors that affect coil impedance
  - 3.1.1 Test part
  - 3.1.2 Test system
- 3.2 Selection of test frequency
  - 3.2.1 Relation of frequency to type of test
  - 3.2.2 Consideration affecting choice of test
    - 3.2.2.1 SNR
    - 3.2.2.2 Phase discrimination
    - 3.2.2.3 Response speed
    - 3.2.2.4 Skin effect
- 3.3 Coupling
  - 3.3.1 Fill factor
  - 3.3.2 Liftoff
- 3.4 Field strength
  - 3.4.1 Permeability changes
  - 3.4.2 Saturation
  - 3.4.3 Effect of AC field strength on eddy current testing
- 3.5 Comparison of techniques
- 3.6 Standardization
  - 3.6.1 Techniques
  - 3.6.2 Reference standards
- 3.7 Techniques – general
  - 3.7.1 Thickness
  - 3.7.2 Sorting
  - 3.7.3 Conductivity
  - 3.7.4 Surface or subsurface flaw detection
  - 3.7.5 Tubing

4.0 Interpretation/Evaluation
- 4.1 Flaw detection
- 4.2 Sorting for properties
- 4.3 Thickness gauging
- 4.4 Process control
- 4.5 General interpretations

5.0 Procedures

Remote Field Testing

1.0 RFT Principles and Theories
- 1.1 Three zones in RFT
  - 1.1.1 Near field (direct field)
  - 1.1.2 Transition zone
  - 1.1.3 Remote field zone
- 1.2 Through-transmission nature of RFT
- 1.3 Standard depth of penetration factors
  - 1.3.1 Thickness
  - 1.3.2 Permeability
  - 1.3.3 Conductivity
  - 1.3.4 Frequency
  - 1.3.5 Geometry

1.4 Signal analysis
1.5 Display options
1.5.1 Voltage plane (polar coordinates)
1.5.2 X-Y display (rectilinear coordinates)
1.5.3 Chart recordings – phase, log-amplitude, magnitude, X-Y
1.6 Advanced applications
1.6.1 Array probes
1.6.2 Large pipes
1.6.3 Flat plates
1.6.4 Nonferrous applications
1.6.5 Effects of tilt and shields
1.6.6 Effects of cores and magnets

2.0 Codes and Practices
2.1 Writing procedures
2.2 ASTM E2096
2.3 SNT-TC-1A
2.3.1 Responsibility of Level III
2.4 Supervision and training
2.5 Administering exams
2.6 Ethics
2.7 Reports – essential elements, legal responsibility

Alternating Current Field Measurement Testing

1.0 Principles and Theory
1.1 Generation of eddy currents
1.2 Effect of fields created by eddy currents
1.3 Properties of eddy currents
1.3.1 Depth of penetration
1.3.2 Effects of test-part characteristics
1.3.3 Current flow
1.3.4 Frequency
1.3.5 Effects of permeability variations
1.3.6 Effects of discontinuity orientation

2.0 Equipment and Materials
2.1 Alternating current measurement probes, general
2.1.1 Advantages and limitations
2.2 Factors affecting choice of probes
2.2.1 Type of part to be inspected
2.2.2 Type of discontinuity to be inspected
2.2.3 Speed of testing required
2.2.4 Amount of testing required
2.2.5 Probable location of discontinuity
2.2.6 Applications other than discontinuity detection
2.3 Techniques/equipment sensitivity
2.3.1 Selection of test frequency
2.3.2 Selection of correct probe scalings in relation to the test
2.3.3 Selection of correct communication rates

3.0 Interpretation and Evaluation of Signals
3.1 Flaw detection

4.0 Procedures

ELECTROMAGNETIC TESTING METHOD LEVEL I, II, AND III TRAINING REFERENCES

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ADDITIONAL PAPERS

The following selected papers are available from PCN Certification Services, British Institute of NDT, 1 Spencer Parade, Northampton NN1 5AA. The list of available papers may be extended by the addition of later publications. This document will not be revised to show the extended list in every case.

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* Available from The American Society for Nondestructive Testing Inc., Columbus, OH.