AECL 7524

2

AECL-7524

ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

EDDY CURRENT MANUAL
VOLUME 2
LABORATORY EXERCISES AND DEMONSTRATIONS

Manuel sur le courant de Foucault
Volume 2
Exercices et démonstration en laboratoire

V.S. CECCO, G. Van DRUNEN and F.L. SHARP

Chalk River Nuclear Laboratories
Laboratoires nucléaires de Chalk River

Chalk River, Ontario

September 1984 septembre

AECL 7524

AECL-7524 C1

ATOMIC ENERGY OF CANADA LIMITED

EDDY CURRENT MANUAL
Volume 2
LABORATORY EXERCISES AND DEMONSTRATIONS

by

V.S. Cecco, G. Van Drunen and F.L. Sharp

ERRATA

Please replace page 113 of the above report with the attached revised page.

Special Projects Division
Chalk River Nuclear Laboratories
CHALK RIVER, Ontario KOJ 1J0

MARCH 1985

4.37 (II) For most eddy current tests, the minimum acceptable signal-to-noise ratio is usually considered to be:

a.	1:2	c.	3:1
b.	1:1	d.	6:1

4.38 (II) The signal displayed on the eddy current instrument storage monitor or on impedance diagrams is the:

a. output bridge unbalance AC (sinusoidal) signal
b. current signal (Y) plotted against the voltage signal (X) since voltage leads current by 90°
c. detected signal displayed by plotting the quadrature components on the X and Y axes simultaneously
d. output bridge unbalance AC signal against the excitation AC signal

4.39 (II) When testing with a differential probe, the signal from a localized defect looks similar to a figure 8 on an X-Y display or a plus-minus signal on a strip chart recorder. This is attributed to the two coils being:

a. wound in opposition
b. wound in addition
c. connected on adjacent legs of the AC bridge
d. connected on the same leg of the AC bridge

4.40 (II) Conductivity instruments normally operate at pre-selected bridge unbalance to:

a. maximize output signal for a given % change in probe impedance
b. minimize lift-off signal
c. increase depth of penetration
d. all of the above

4.41 (II) Effects of capacitance are not normally considered in eddy current testing except when:

a. cable length is excessive
b. inspection is done under water
c. low test frequencies are used
d. instrument is not grounded

4.42 (III) Constant current send-receive eddy current instruments are preferred, over the conventional impedance instruments, for absolute measurements such as resistivity and plating thickness, because:

a. higher penetration is achieved at the same test frequency due to higher excitation currents
b. output signal is less affected by changes in coil temperature
c. they are less sensitive to distortions in the excitation signal
d. all of the above

4.43 (III) Which of the following is NOT a method that may generally be used to improve signal-to-noise ratio?

a. change to a test frequency that will decrease the noise
b. increase amplification of the test instrument
c. increase fill factor
d. add filter circuits to the instrument
e. magnetically saturate the material during inspection

4.44 (III) Two test coils are often used in a bridge circuit to:

a. increase depth of penetration
b. make possible bridge balance
c. increase the conductivity of the circuit
d. decrease the system sensitivity
e. double the bridge inductance

4.45 (III) Crack detectors normally used for defect detection on high electrical resistivity materials, such as stainless steel, could be used to:

a. detect subsurface cracks in aluminum
b. detect surface cracks in brass
c. measure wall thickness in airplane wings
d. sort materials with low electrical resistivity
e. none of the above

4.46 (III) Crack detectors cannot be used to detect deep subsurface defects, primarily because:

a. they have no lift-off compensation
b. they operate at a single high test frequency, thereby limiting eddy current penetration
c. they have only a meter output
d. they are very sensitive to material's resistivity variations
e. the meter output has insufficient range

4.47 (III) When a general purpose bridge type eddy current instrument is used with an input impedance of 75 ohms,

a. a probe impedance of 75 ohms should not be used because of possible probe-instrument resonance
b. a probe impedance at least 500 ohms should be used to ensure a high probe excitation voltage
c. a probe impedance less than 5 ohms should be used to ensure a high probe excitation current
d. a probe impedance between 15 and 200 ohms will work satisfactorily except at probe-cable resonance
e. none of the above

5&6.48 (I) Lift-off is utilized in:

a. measuring permeability changes
b. measuring conductivity changes
c. measuring the thickness of non-conductive coatings
d. determining proper test frequency

ATOMIC ENERGY OF CANADA LIMITED

EDDY CURRENT MANUAL

VOLUME 2

LABORATORY EXERCISES AND DEMONSTRATIONS

V.S. Cecco, G. Van Drunen and F.L. Sharp

Nondestructive Testing Development Branch
Chalk River Nuclear Laboratories
CHALK RIVER, Ontario KOJ 1JO

1984 SEPTEMBER

AECL-7524

L'ENERGIE ATOMIQUE DU CANADA, LIMITEE

Manuel sur le courant de Foucault
Volume 2

Exercices et démonstration en laboratoire

V.S. Cecco, G. Van Drunen et F.L. Sharp

Résumé

Le présent rapport sur les essais du courant de Foucault se divise en trois sections: (a) Démonstration des principes de base (b) Essais pratiques (en laboratoire) et (c) Questions types de l'examen d'agrément. Il servira de supplément au "Manuel sur le courant de Foucault, Volume I" lors des cours de niveau II et III de la Société canadienne pour les essais non destructifs.

Les démonstrations en laboratoire servent à illustrer les principes de base. Elles complètent et même remplacent parfois les dérivations mathématiques vues dans le volume 1. L'instrumentation complexe est subdivisée en unités plus simples afin d'illustrer les fonctions importantes. Le champ magnétique et le débit du courant de Foucault sont expliqués au moyen de modèles simples.

Les essais pratiques ont été conçus pour familiariser les étudiants avec le maniement des appareils et avec l'exécution de certains essais types. Ils incluent le mesurage de l'impédance des sondes, des essais avec des sondes de surface et l'inspection de tubes d'échangeurs de chaleur. La complexité de ces essais est égale, sinon supérieure, à celles des essais de l'examen pratique du niveau II ET de l'Office des normes générales du Canada (ONGC).

On utilise des échantillonnages de questions à choix multiple pour vérifier si l'étudiant a compris la matière des cours. Ils sont subdivisés et numérotés selon les chapitres du volume 1 et ils se subdivisent plus encore conformément aux niveaux d'agrément I, II et III de l'ONGC. Ils devraient s'avérer utiles en préparant les étudiants aux examens écrits de l'ONGC.

Département du développement des essais non destructifs
Laboratoires nucléaires de Chalk River
Chalk River (Ontario) KOJ 1JO

Septembre 1984

AECL-7524

ATOMIC ENERGY OF CANADA LIMITED

EDDY CURRENT MANUAL
VOLUME 2

LABORATORY EXERCISES AND DEMONSTRATIONS

V.S. Cecco, G. Van Drunen and F.L. Sharp

ABSTRACT

This report on eddy current testing (ET) is divided into three sections: (a) Demonstration of Basic Principles, (b) Practical (Laboratory) Tests and (c) Typical Certification Questions. It is intended to be used as a supplement to "Eddy Current Manual, Volume 1" during CSNDT Foundation Level II & III courses.

Laboratory Demonstrations are used as an aid to illustrate basic principles. They supplement, and in some cases replace, the mathematical derivations covered in Volume 1. The complex instrumentation is subdivided into simpler units to illustrate important functions. Magnetic field and eddy current flow are demonstrated with the help of simple models.

Practical (hands-on) tests are intended to give students practice in using equipment and performing typical tests. They include measurement of probe impedance, tests with surface probes, and inspection of heat exchanger tubes. The complexity of these tests is equivalent to, or surpass, the tests in the Canadian General Standards Board (CGSB) practical exam for Level II ET.

Sample of multiple choice questions are intended to check students' understanding of course material. They are subdivided and numbered according to the chapters in Volume 1 and further subdivided into CGSB certification Levels I, II and III. They should prove useful in preparing students for CGSB written exams.

Nondestructive Testing Development Branch
Chalk River Nuclear Laboratories
CHALK RIVER, Ontario K0J 1J0

1984 SEPTEMBER

AECL-7524

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS (CONTINUED)

PREFACE

The saying "A little knowledge is a dangerous thing" was never more valid than when applied to eddy current testing. As a result, use of this valuable technique has, in the past, often been rejected because of bad experiences resulting from ignorance and inexperience. This course supplement, accompanied by 'Eddy Current Manual', Volume 1*, is intended to reduce the reoccurrence of such situations. A person best learns the eddy current technique by trying his hand at it and, realizing that there can be many pitfalls, discovers early in his career to exercise a degree of caution when tempted to make a hasty conclusion.

A combination of description and direction is used which we have found effective in teaching. The demonstrations and exercises were developed to assist in teaching eddy current courses at Chalk River. They are a result of years of collective experience and have proven to be very effective in helping students acquire a feeling for the eddy current technique.

The original demonstration apparatus and calibration samples are retained at Chalk River Nuclear Laboratories. However, they can be reproduced using the photographs and schematics as a guide, or they can be purchased from Chalk River. It is obviously not essential to reproduce the calibration samples in exact detail; however, caution should be exercised not to inadvertently introduce misleading variables. For instance, 316 stainless steel could be substituted for the zirconium samples in exercises L6.1(a) and (b), but it would need to be vacuum annealed to remove any ferromagnetic effects introduced during defect machining (including EDM).

The authors shall be grateful to those who take the time and effort to report errors they have discovered or who have suggestions for improvement. All such comments will receive consideration for inclusion in future revisions.

---

*V.S. Cecco, G. Van Drunen, F.L. Sharp, "Eddy Current Manual, Volume 1, Test Method", AECL-7523, 1983.

ACKNOWLEDGEMENTS

This report contains an accumulation of practical tests and eddy current questions which evolved over the 13 year existence of the Nondestructive Testing Development Branch (formerly the Quality Control Branch) at the Chalk River Nuclear Laboratories (CRNL) of Atomic Energy of Canada Limited (AECL).

The authors are indebted to the other members of the branch especially W.J. Beattie, J.R. Carter, H.W. Ghent, G.A. Leakey, W. Pantermoller, R. Smit, M.R. Demers and T.J. Mohns who prepared the laboratory equipment

NOMENCLATURE

SYMBOL	QUANTITY	SI UNIT
A	Cross-Sectional area	millimetre^2
r	Radius	millimetre
$\overline{r}$	Average radius	millimetre
ℓ	Length	millimetre
t	Thickness	millimetre
w	Width	millimetre
D	Diameter	millimetre
D_i, D_o, $\overline{D}$	Inside, Outside and Average Diameter respectively	millimetre
B	Magnetic flux density	weber/metre^2 or tesla
C	Capacitance	farada
f	Test frequency	hertz
f_{90}	Optimum tube testing frequency	kilohertz
f_g	Characteristic or Limit frequency	kilohertz
f_r	Resonant frequency	hertz
H	Magnetic field intensity (Magnetizing force)	lenze
I	Current	amperes
J	Current density	amperes/metre^2
L	Self Inductance	henry
N	Number of turns (Windings)	dimensionless
P_c	Characteristic Parameter	dimensionless
Q	Quality factor	dimensionless
R	Resistance	ohm
R_L	Resistive load	ohm
V	Electric potential	volt
x	Depth below the surface	millimetre
X_L	Inductive Reactance	ohm
X_c	Capacitive Reactance	ohm
Z	Impedance	ohm
δ (Delta)	Standard Depth of Pentration	millimetre
μ (Mu)	Permeability	henry/metre
μ_o	Magnetic Permeability in air	henry/metre
μ_r	Relative Magnetic Permeability	dimensionless
ρ (Rho)	Resistivity	microhm-centimetre
σ (Sigma)	Conductivity	siemens/metre
Φ (Phi)	Magnetic flux	weber
η (Eta)	Fill Factor	dimensionless
β (Beta)	Phase Lag	radians
ω (Omega)	Angular frequency	radians/second
Θ (Theta)	Angle between Z & R	degrees

SECTION 1 - LABORATORY DEMONSTRATIONS

This section contains a description of laboratory demonstrations which could be used during an eddy current course. They are intended as an aid to illustrate basic principles and to supplement the mathematical derivations covered in the "Eddy Current Manual, Volume 1".

The section contains demonstrations such as: probe sensing a defect, electromagnetic induction, equivalent circuit, probe impedance, skin depth effect, effect of phase lag on eddy current signal, and typical AC bridge. These demonstrations give the student a direct (visual) appreciation and acceptance of the important eddy current principles and equipment functions without the need of complicated mathematical derivations.

The demonstrations are denoted with a 'D' and numbered to correspond to chapters in the "Eddy Current Manual, Volume 1".

DEMONSTRATION OF A PROBE SENSING A DEFECT
No. D2.1

INTRODUCTION: In this demonstration it will be shown that a defect can be detected using an oscillator, voltmeter and probe.

EQUIPMENT:

1) A brass plate with a groove cut into it and a large diameter surface probe (2.5 cm diameter or larger)
2) HP651B test oscillator or equivalent
3) Digital voltmeter

PROCEDURE:

1) Set the frequency of the oscillator to 10 kHz.
2) Adjust the voltage level until the voltage across the probe is about 100 mV when the probe is coupled to the plate.
3) Slowly move the probe across the groove (it is moved slowly because the meter has a slow response).

RESULTS: As the probe was moved across the large defect the voltage changed by about 0.5 mV, indicating its presence. According to Ohm's Law, V = IZ and therefore probe impedance, Z, changed by approximately 0.5% in the presence of the large defect. This value changes with test frequency and probe diameter.

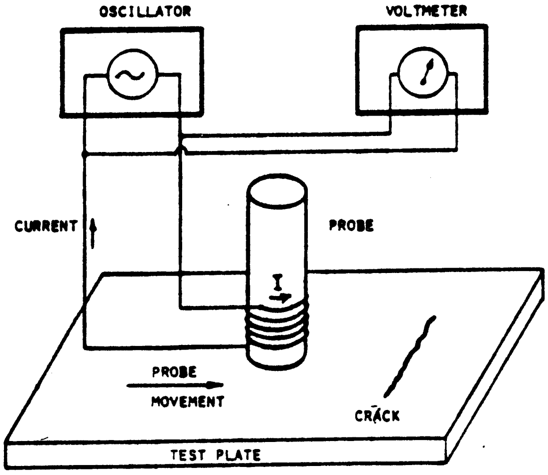


Fig. 1: Eddy Current Test Equipment

NOTES

DEMONSTRATION OF ELECTROMAGNETIC INDUCTION
No. D2.2

INTRODUCTION:	When an eddy current probe is inserted into a tube, eddy currents are caused to flow in that tube via electromagnetic induction.
EQUIPMENT:	1) Electromagnetic induction unit (Figure 1). 2) Eddy current probe (Figure 2). 3) Eddy current instrument.
PROCEDURE:	1) Turn on unit (switch underneath). 2) Plug probe into eddy current instrument; connect B and C as shown in schematic, Figure 3. 3) Set frequency between 5 kHz and 20 kHz. 4) Insert probe into tube.
RESULTS:	There is a sinusoidal current flowing through the probe with an associated varying magnetic field around the probe. This magnetic field induces eddy currents into the tubing. The induced current is fed to an amplifier. The amplifier drives a lamp which only illuminates when eddy currents flow in the tubing.

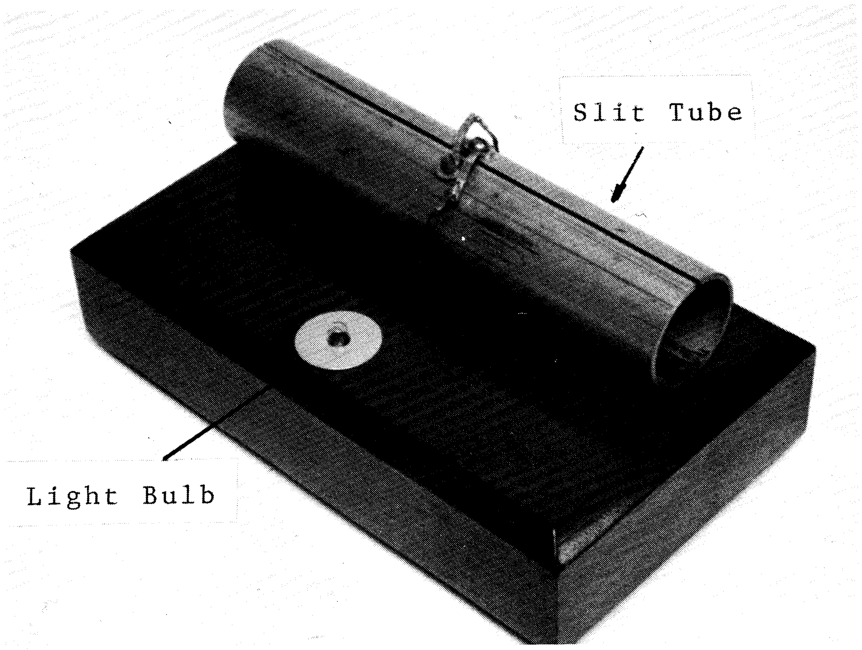


Fig. 1: Electromagnetic Induction Unit

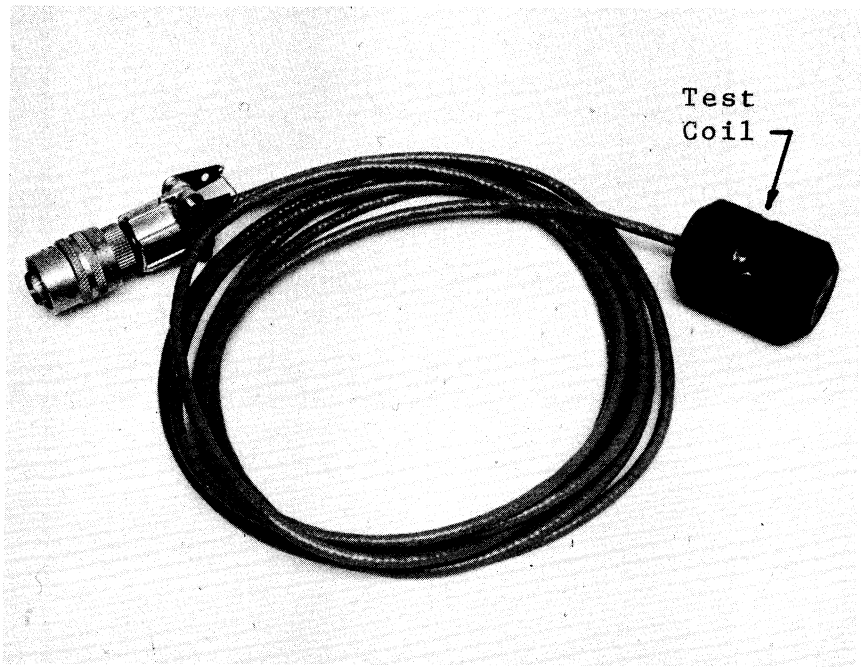


Fig. 2: Eddy Current Probe

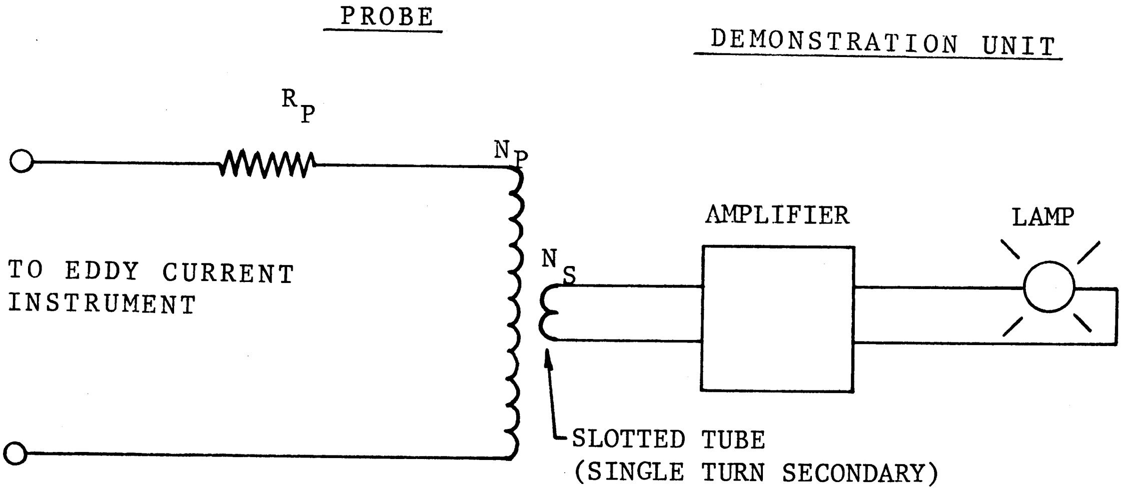


Fig. 3: Electrical Schematic of Equivalent Circuit

DEMONSTRATION OF ATTENUATION OF EDDY CURRENTS WITH DISTANCE

NO.D2.3

INTRODUCTION:	The signal amplitude from a defect decreases with defect-to-coil distance or subsurface defect depth. This demonstration shows how induced voltage depends on distance to the excitation coil. On this model there are two sensing coils for detecting the field generated by the probe coil; they can be considered as simulating defects at that location. The top coil, which is stationary, simulates a surface defect; the other coil simulates a subsurface defect, the position of which is variable.
EQUIPMENT:	1) Signal generator (e.g. HP651B test oscillator) 2) Dual trace oscilloscope 3) Depth demonstration unit (Figure 1) 4) An eddy current probe
PROCEDURE:	1) See Electrical Schematic, Figure 2. 2) Connect B and C of the eddy current probe to the output of the oscillator 3) Adjust the oscillator FREQUENCY to 10 kHz and the ATTENUATOR switch to 3.0V. Using the COARSE dial adjust the meter reading to about mid scale (can be increased or decreased as desired). 4) Connect the coils of the demonstration unit to the oscilloscope, each coil to its own vertical input amplifier 5) Place the probe in the indentation on top of the plexiglass 6) Move lower plexiglass up and down.
RESULTS:	The signal amplitude on the coil closest to the probe will remain the same, but the amplitude on the other coil will decrease when the two coils are separated. The signals are illustrated on the CRT display of Figure 3. The induced currents in the two coils on the demonstration unit will always be in-phase with each other. There is no time delay in the magnetic field between the two coils because the magnetic field around the probe is basically only set up in air.

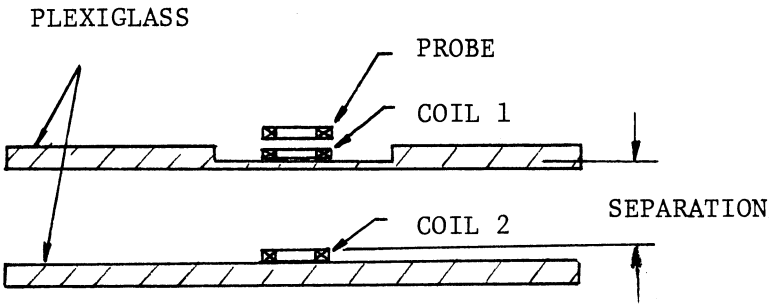


Fig. 1: Cross-Section of Depth Demonstration Unit Showing Coils Positions

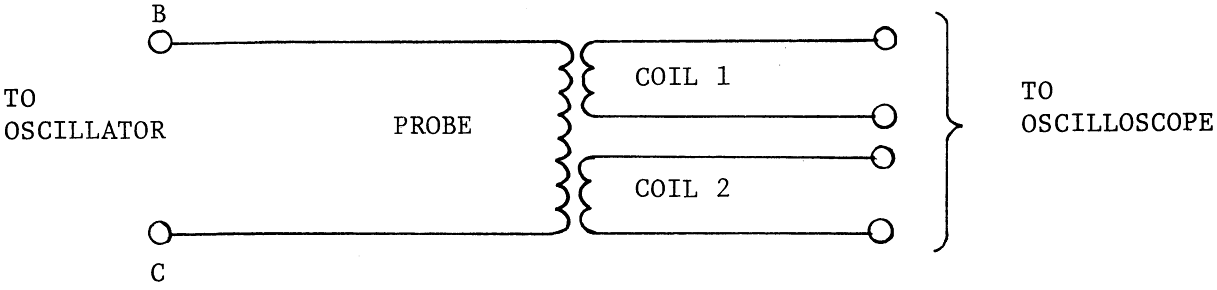


Fig. 2: Electrical Schematic

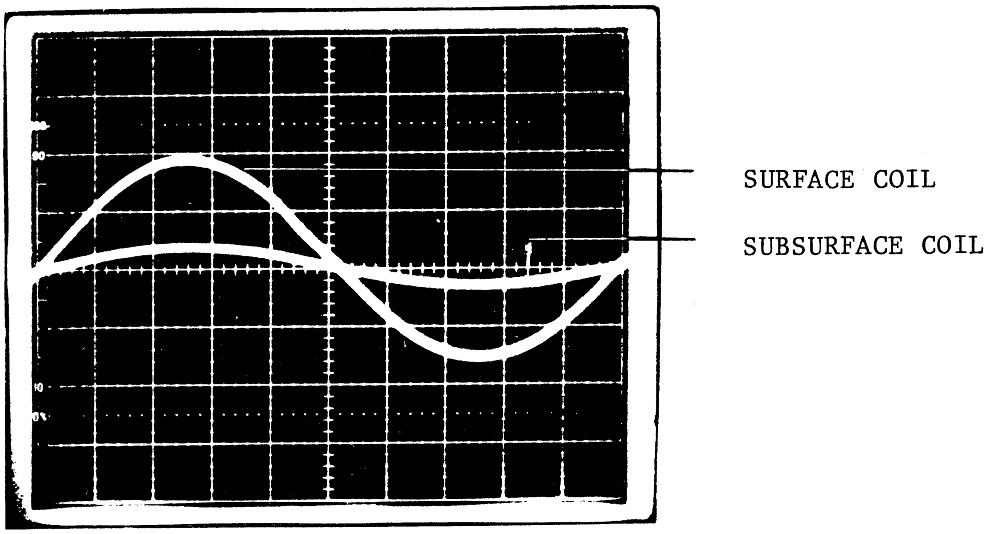


Fig. 3: CRT Display Illustrating Signals from Surface and Subsurface Coils

DEMONSTRATION OF PHASE LAG OF EDDY CURRENTS WITH DEPTH

NO.D2.4

INTRODUCTION: The magnetic flux and eddy current density decreases as the subsurface defect gets deeper, as demonstrated in D2.3. In this case there is also a phase shift because the magnetic field passes through metal (brass) rather than air. In this demonstration there are three coils simulating defects. One surface and two subsurface defects. The subsurface defect is at $X_1 = 0.26$ mm from the surface and the other at $X_2 = 1.3$ mm.

EQUIPMENT:

1) Signal generator (e.g. HP651B test oscillator).
2) Four trace oscilloscope
3) Phase lag demonstration unit (Figure 1)

PROCEDURE:

1) See Electrical Schematic, Figure 2(a) and 2(b)
2) Adjust the oscillator ATTENUATOR switch to 3.0V and, using the COARSE dial, adjust the meter reading to full scale.
3) Adjust FREQUENCY to 40 kHz.
4) Connect the Probe coil to the oscillator.
5) Connect coils 1, 2, and 3 of the demonstration unit to the oscilloscope, each coil to its own vertical input amplifier.

RESULTS: At any frequency the signal from the subsurface defect 1.3 mm deep is shifted in phase approximately five times as much as the one 0.26 mm deep, Figure 3. The phase shift is due to the time delay in the eddy currents passing through the metal plates, (e.g. at $f=40$ kHz, $\beta x_1=36^\circ$, $\beta x_2=158^\circ$).

Together with the phase shift there is also a decrease in signal amplitude as the defect gets further below the surface as demonstrated in D2.3.

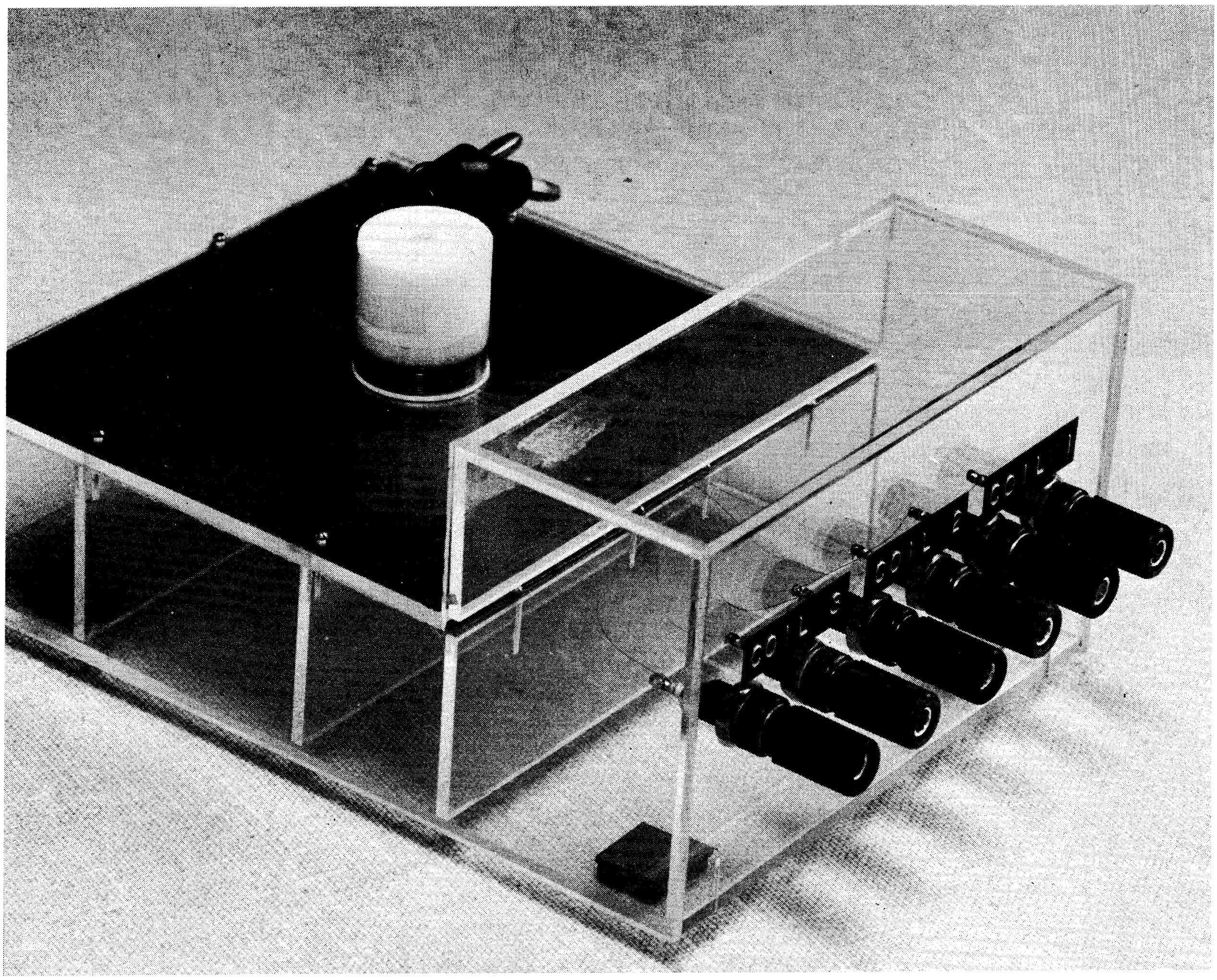


Fig. 1: Phase Lag Demonstration Unit

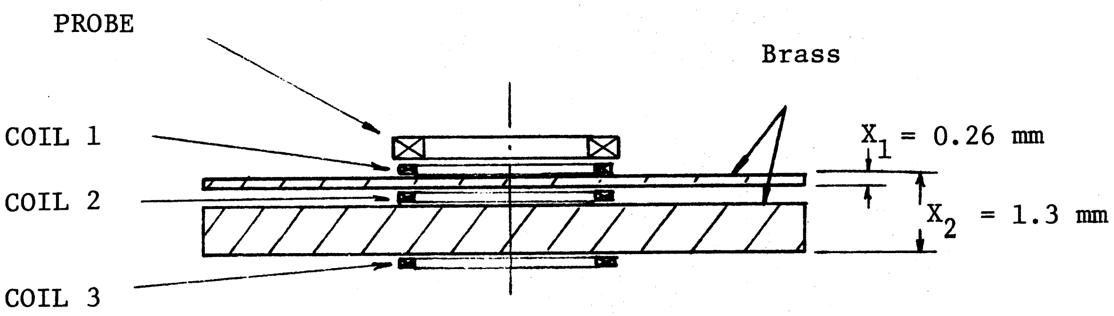


Fig. 2(a): Cross-Section of Phase Lag Demonstration Unit Showing Coil Positions

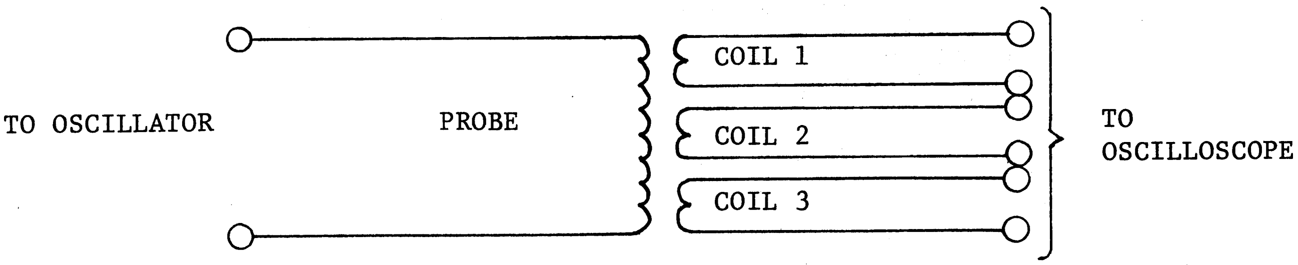


Fig. 2(b): Electrical Schematic

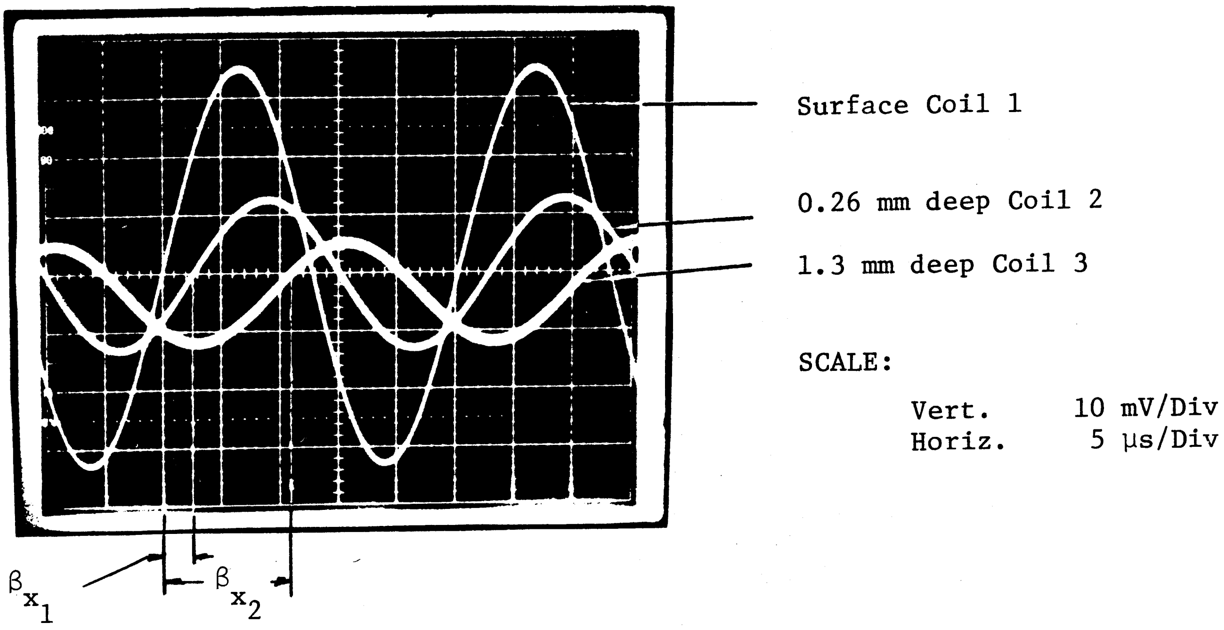


Fig. 3: CRT Display Showing Phase Lag Between Surface and Subsurface Defects (Represented by Coils). f=40 kHz

NOTES

DEMONSTRATION OF IMPEDANCE LOCUS OF A RESISTOR IN PARALLEL WITH AN INDUCTOR

NO. D3.1

PURPOSE: To illustrate that the impedance locus of a resistor in parallel with an inductor is a semi-circle.

EQUIPMENT:
1) Eddy current instrument EM3300 or equivalent, Figure 1.
2) Inductor-resistor network, Figure 2.

PROCEDURE: 1) Set up eddy current instrument as follows:

FREQUENCY	90 kHz
VERTICAL	0.5 V/Div
HORIZONTAL	0.5 V/Div
SENSITIVITY	4%
R Balance pot	5.00
X Balance pot	5.00

2) Check that the variable resistor is in the fully counterclockwise position.

3) Adjust the instrument phase until the dot on the storage monitor traces a vertically upward line when a ferrite sample is brought close to the inductor.

4) Turn the variable resistor clockwise and observe the trace on the instrument monitor.

RESULTS: Clockwise rotation of the variable resistor simulates an increase in resistance to eddy current flow and produced a semi-circular trace on the eddy current monitor, as seen in Figure 1.

The trace resembles that produced by varying the secondary resistive load, demonstration D3.2 or by varying the electrical resistivity of a test sample. This validates the parallel equivalent circuit model of a probe adjacent to a conductor.

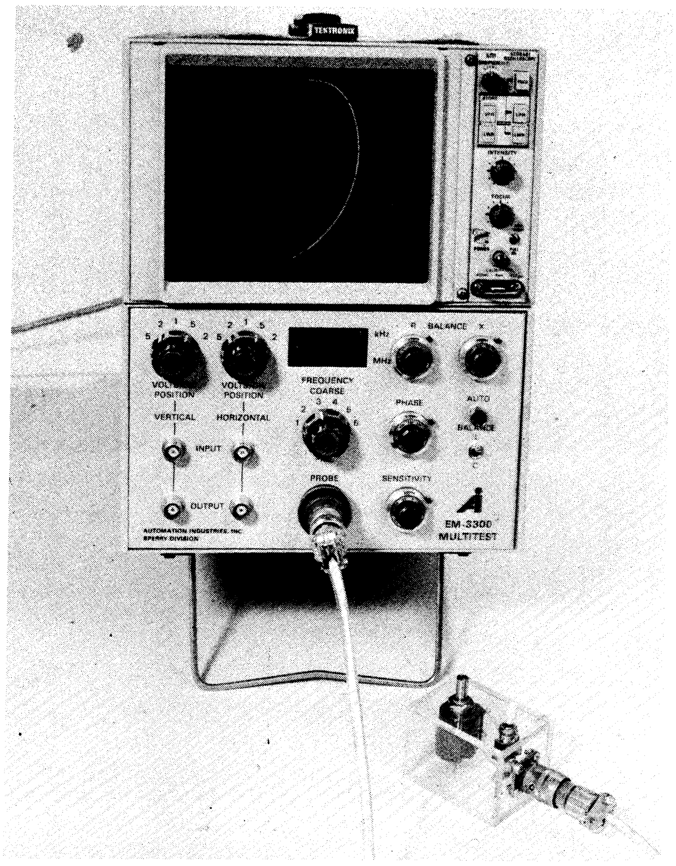


Fig. 1: Eddy Current Instrument & Resistor-Inductor Unit

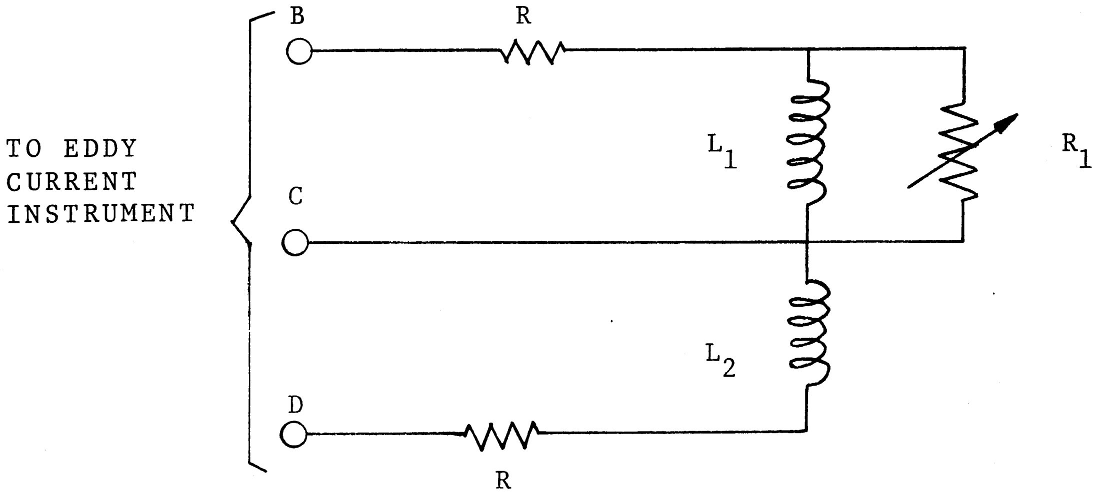


Fig. 2: Electrical Schematic

DEMONSTRATION OF EFFECT OF SAMPLE RESISTANCE ON PROBE IMPEDANCE
No. D3.2

INTRODUCTION: The effect of electrical resistivity variations on an eddy current impedance display can be demonstrated using a slotted tube with a variable resistor connected across the slot.

EQUIPMENT:

1) Electrical resistivity demonstration unit (Figure 1).
2) Eddy current probe (Figure 2).
3) Eddy current instrument (Figure 3).

PROCEDURE:

1) See Electrical Schematic, Figure 4.
2) Set up instrument as follows:
   - FREQUENCY 300 kHz
   - SENSITIVITY 10%
   - Scale: VERTICAL 2 V/Div., HORIZONATAL 2V/Div.
3) Turn the variable resistor on the demonstration unit fully counter-clockwise (zero resistance).
4) Insert eddy current probe into tube.
5) Balance the eddy current instrument and position the operating point (CRT Dot) near the bottom centre of the screen.
6) Adjust the PHASE CONTROL for a vertically upward CRT trace when a ferrite sample is inserted into the tube.
7) Turn the variable resistor on the demonstration unit clockwise.

RESULTS: Clockwise rotation of the resistor increases resistance to eddy current flow and produces a trace similar to that shown on the CRT screen in Figure 3. This trace closely resembles the impedance diagram in Figure 5. It demonstrates increasing resistivity raises the operating point on the impedance plane.

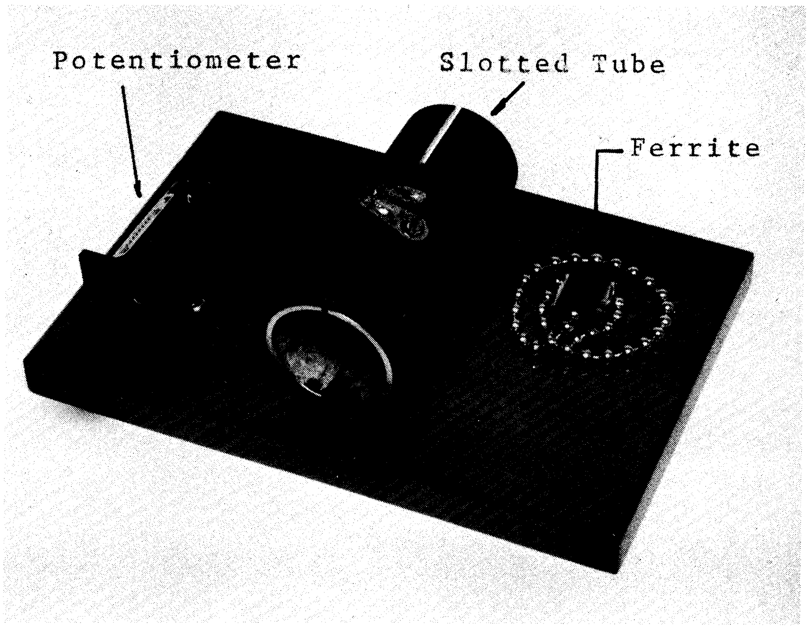


Fig. 1: Electrical Resistivity Demonstration Unit

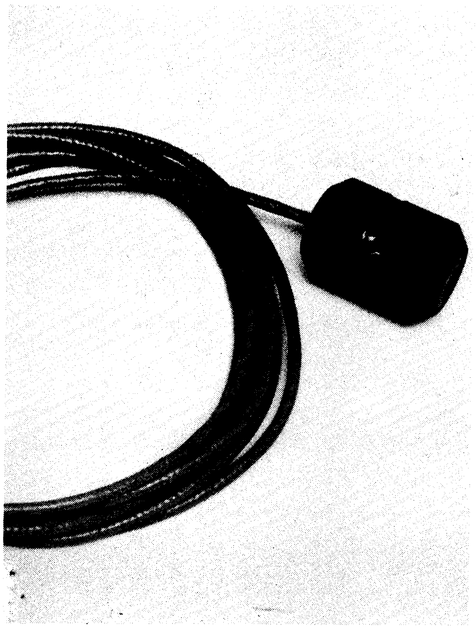


Fig. 2: Eddy Current Probe

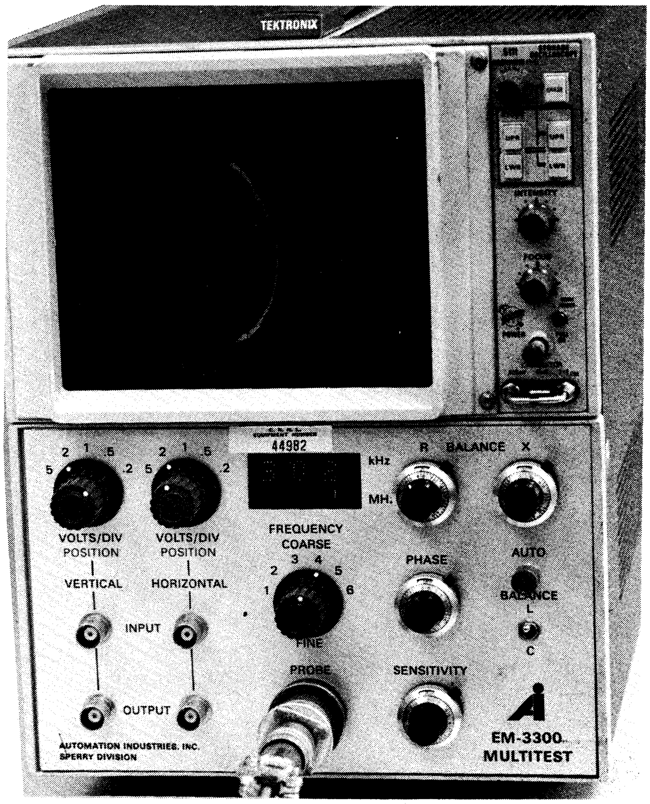


Fig. 3: Eddy Current Instrument

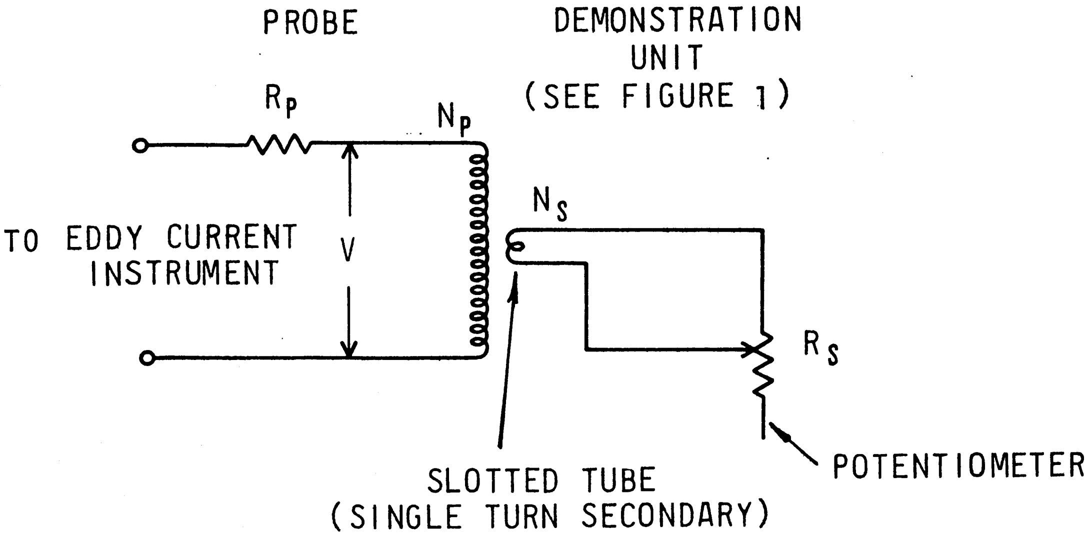


Fig. 4: Electrical Schematic

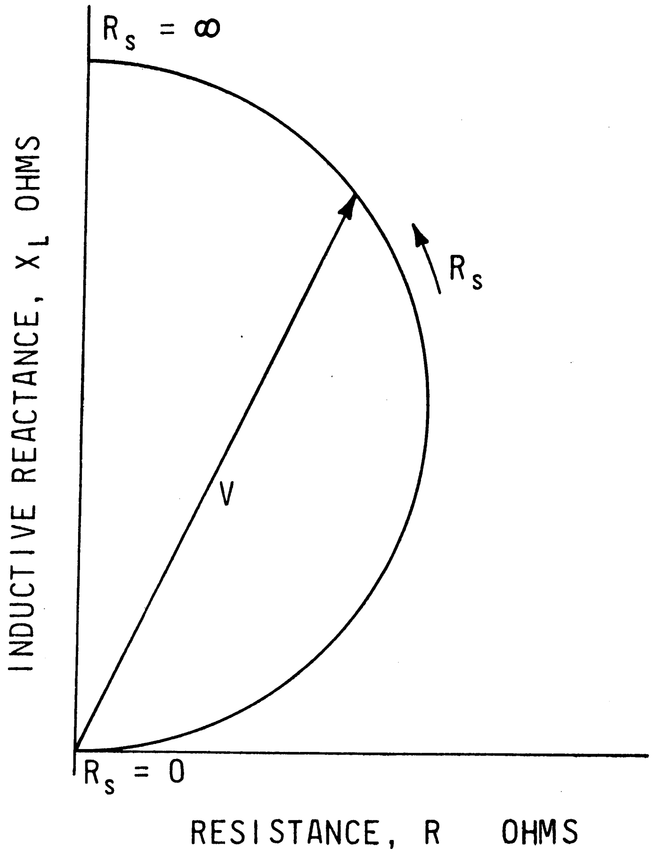


Fig. 5: Impedance Diagram

NOTES

DEMONSTRATION OF QUADRATURE COMPONENTS ON EDDY CURRENT INSTRUMENT

NO. D3.3

INTRODUCTION: In an AC circuit containing inductors and resistors in series, there is a phase shift in the voltage across the various components (in parallel circuits the phase shift is in the currents). This phase shift corresponds to a ccw rotation of the signal on the eddy current monitor.

EQUIPMENT:

1) RL demonstration unit (Figure 1).
2) Dual trace oscilloscope, Tektronix 7704 or equivalent.
3) Eddy Current instrument, EM3300 or equivalent.

PROCEDURE:

1) See electrical schematic, Figure 2.
2) Connect eddy current instrument to RL demonstration unit through plug labelled BCD.
3) Adjust test frequency to 12.5 kHz.
4) Set BALANCE controls to 5.0.
5) Connect BNC connector labelled B'C' on RL demonstration unit to channel 1 of oscilloscope.
6) Connect BNC connector labelled D'C' to channel 2 of oscilloscope.
7) Set TIME BASE triggering to 20 µsec/div.
8) Set oscilloscope to ADD mode. Since the voltages across B'C' will be 180° out-of-phase to each other, adding the two signals will display bridge unbalanced.
9) Adjust the variable resistor and variable inductor to minimize the unbalance voltage, as seen in Figure 3(a).
10) Increase resistance (R_2) by approximately 40%. Waveform peak-to-peak amplitude should increase to approximately 0.8V, as seen in Figure 3(b).
11) Return to balance state (Figure 3(a)).
12) Increase inductance (L_2) by approximately 40% (5 turns). Waveform amplitude should increase to approximately 0.8 V, as seen in Figure 3(c). Note that the waveform leads that from an increase in resistance, Figure 3(b), by 90°.
13) Return to balance state (Figure 3(a)).
14) Set eddy current instrument SENSITIVITY to approximately 0.5%. Set monitor controls to 2 V/div.
15) Adjust the PHASE CONTROL to display a horizontal line to the right with an increase in resistance (R_2).
16) Increase resistance in the RL demonstration unit by approximately 40% and observe the signal on the eddy current monitor, Figure 3(c). Decrease the resistance to original value.

17) Increase inductance by approximately 40% (5 turns) and observe the signal on the monitor. The signal from an increase in inductance is approximately 90° ccw to that from an increase in resistance, as seen in Figure 3(d).

RESULTS: (a) Observe the waveforms on the oscilloscope. The voltage across the inductor leads the voltage across the resistor by 90°.

(b) Observe the unbalance signal on the eddy current storage monitor. The signal from a change in inductance is rotated 90° ccw from the change in resistance signal. This 90° phase rotation agrees with the phase shift seen on the oscilloscope.

CONCLUSION: The eddy current instrument displays the quadrature components of the unbalance AC eddy current signal.

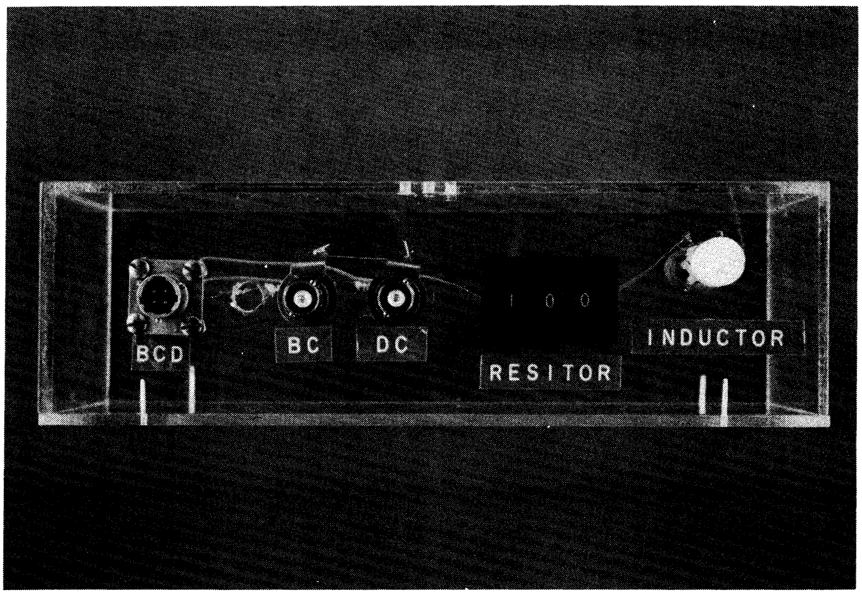


FIGURE 1: RL Demonstration Unit

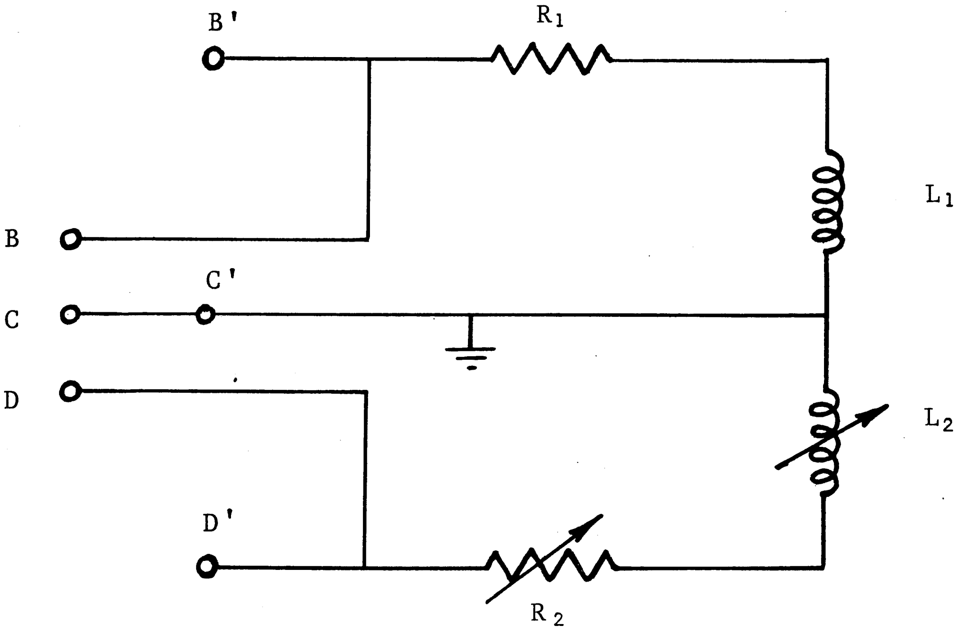
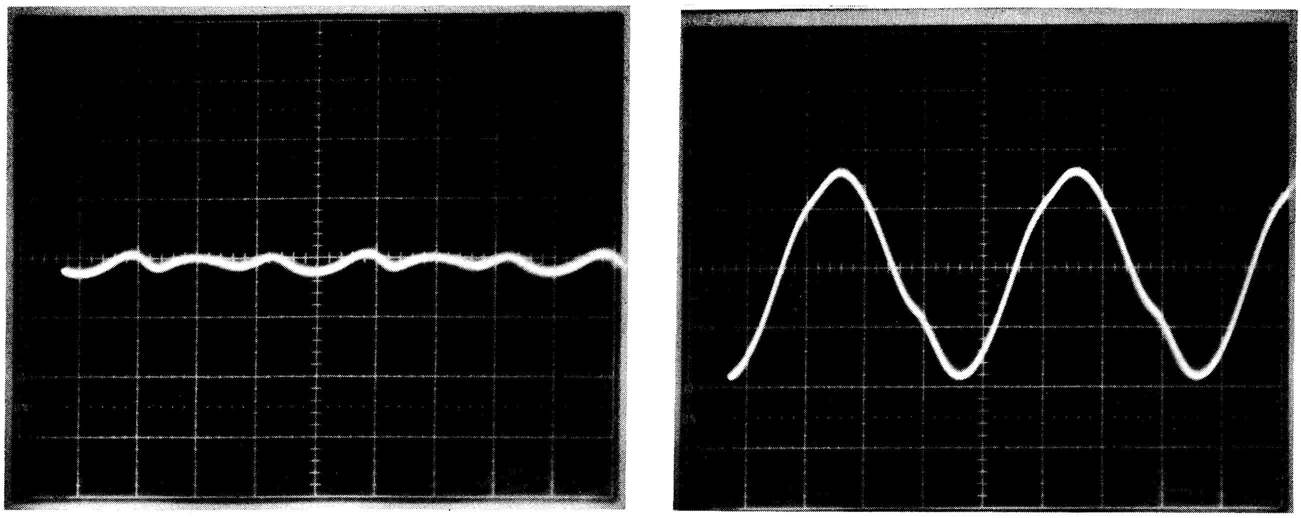
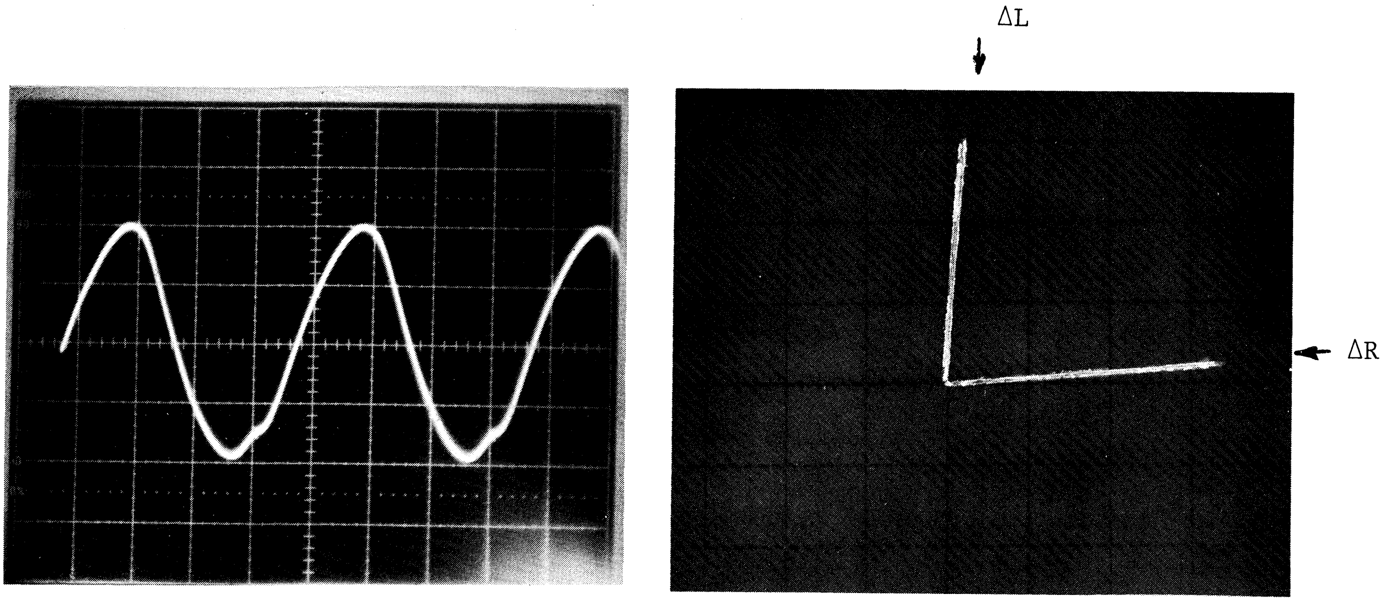


FIGURE 2: Electrical Schematic of RL Demonstration Unit



(a) Bridge Balanced

(b) Bridge Unbalance, ΔR



(c) Bridge Unbalance, ΔL

(d) Eddy Current Instrument Display of Bridge Unbalance

FIGURE 3: (a), (b), and (c) Oscilloscope Display of AC Bridge Output
(d) Eddy Current Instrument Display of Bridge Output

DEMONSTRATION OF BASIC AC BRIDGE
NO. D4.1

INTRODUCTION: This demonstration shows the operating principles of an AC bridge.

EQUIPMENT:

1) AC bridge (Figure 2)
2) Signal generator (WAVE TECK Model 112 or equivalent)
3) Dual trace oscilloscope.

PROCEDURE:

1) Set the signal generator FREQUENCY at 10 kHz sinusoidal output and adjust amplitude to 2 V P-P.
2) Connect the bridge input to one beam of the oscilloscope and the output to the other beam.

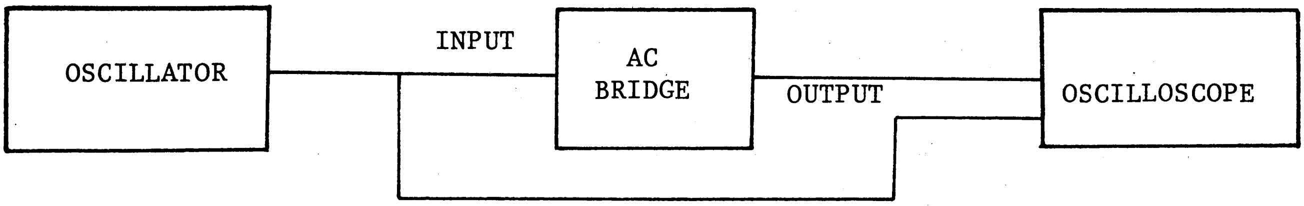


Fig. 1: Block Diagram Showing Connections

RESULTS:

(a) Balancing with impedance components

The bridge may be balanced by adjusting the R and X controls as shown in Figure 2. The inductors L1 and L2 represent the windings of a two coil eddy current probe and variable resistors represent the resistance of the windings (or resistive load when coupled into a test sample)

From Figure 3, balance is obtained when:

$$\frac{R_1}{R_2} = \frac{Z_3}{Z_4}$$

where

$$Z_3 = \frac{R_3(R_5+r_1+jX_1)}{R_3+R_5+r_1+jX_1}$$

$$Z_4 = \frac{R_4(R_6+r_2+jX_2)}{R_4+R_6+r_2+jX_2}$$

r_1 = resistance of coil L1
r_2 = resistance of coil L2

X_1 = inductive reactance of coil L1
X_2 = inductive reactance of coil L2

(b) Unbalancing with impedance components	When the bridge has been balanced, i.e. the output is zero, decreasing the inductance of inductor L1 by turning out the ferrite slug causes an out-of balance condition where the output AC signal leads the input signal. When decreasing the inductance of inductor L2 an out-of-balance condition occurs where the output signal lags the input signal. These conditions can also be simulated by placing a metal tube over one inductor at a time. The bridge is also put out-of-balance by changing the DC resistance i.e. R5 and R6.
(c) Balancing With Probe	Inductors L1, L2 and associated resistors R5 and R6 may be replaced by an eddy current probe. The actuator switch SW1 is moved to the right and DIFFERENTIAL (or ABSOLUTE with an internal ref) probe connected to J3. The effects of the R and X CONTROLS can then be observed under actual operating conditions.
(d) Effect of Frequency and Resonance	A probe on a long cable (30 m) is connected to J3. The bridge is initially balanced at 10 kHz. As the frequency is increased an out-of-balance condition occurs where the output signal leads the input signal. At about 250 kHz the output is in-phase with the input. This is known as the probe-cable resonance frequency, and at this frequency the bridge cannot be balanced. As the frequency is raised, the output lags the input and the bridge can again be balanced. The probe/cable combination appears as a capacitive load to the bridge.

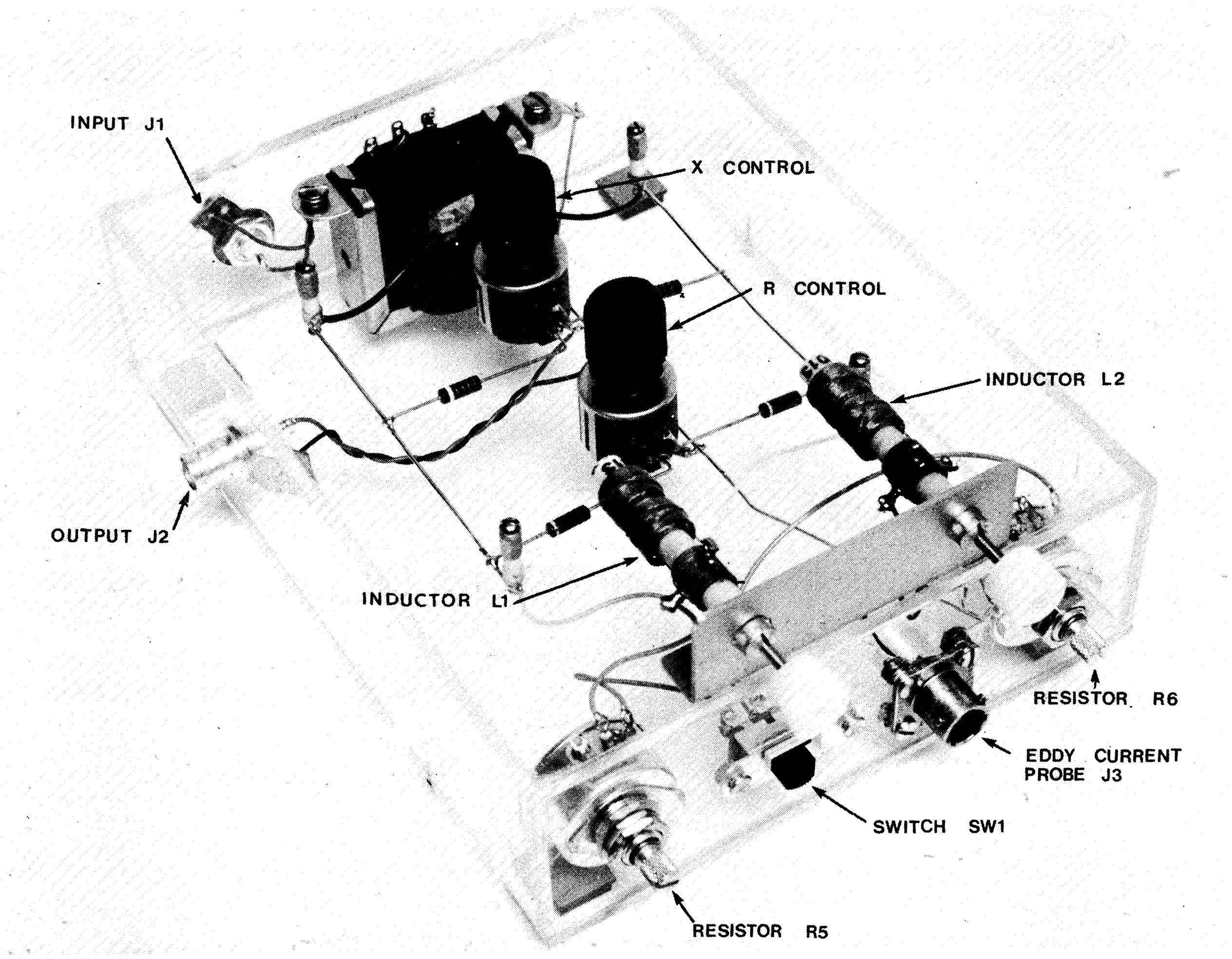


FIG. 2: AC Bridge Demonstration Unit

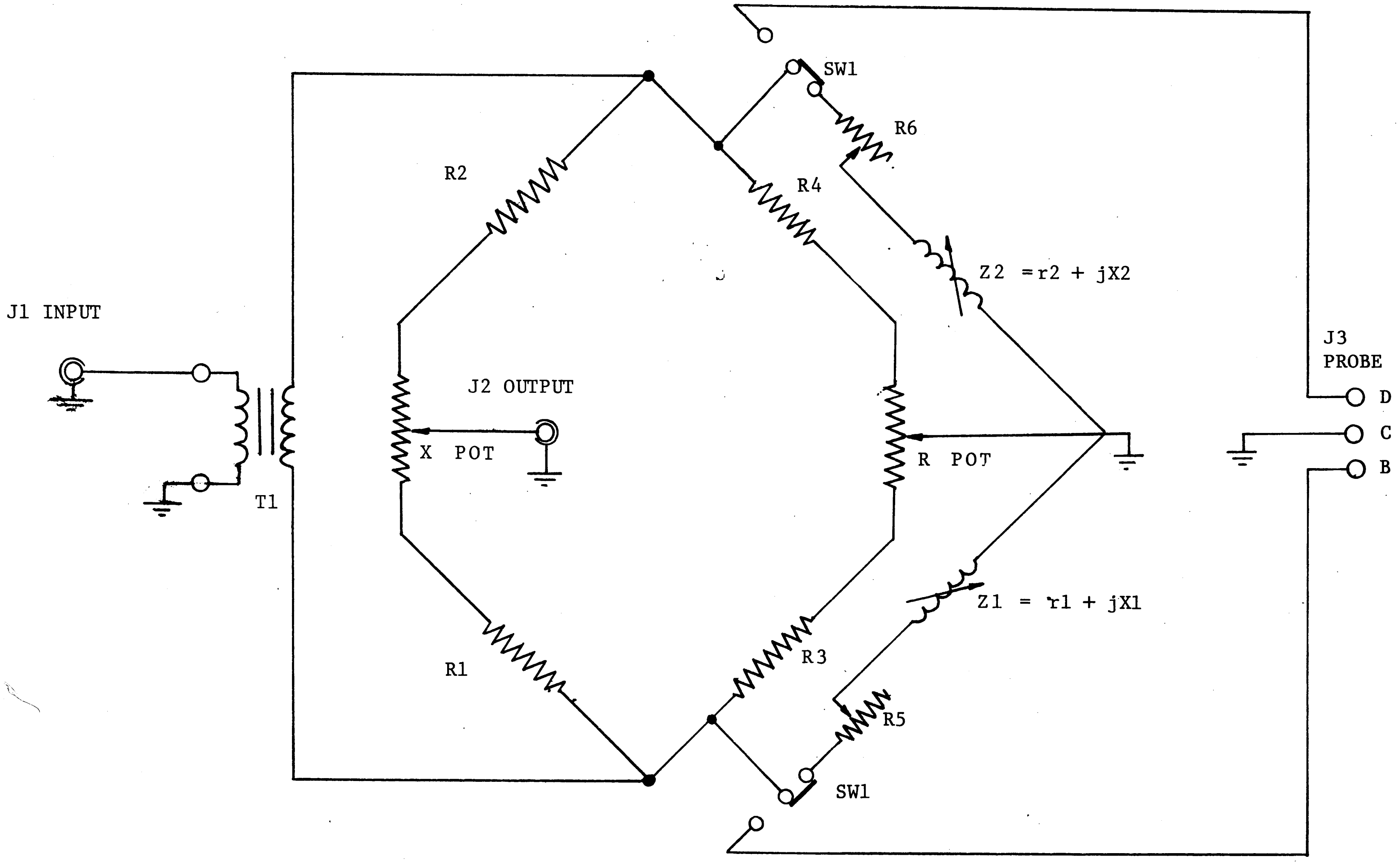
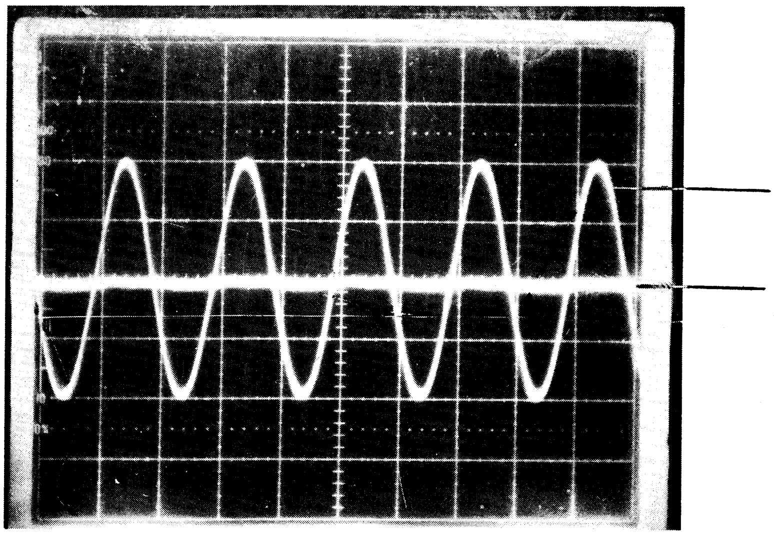
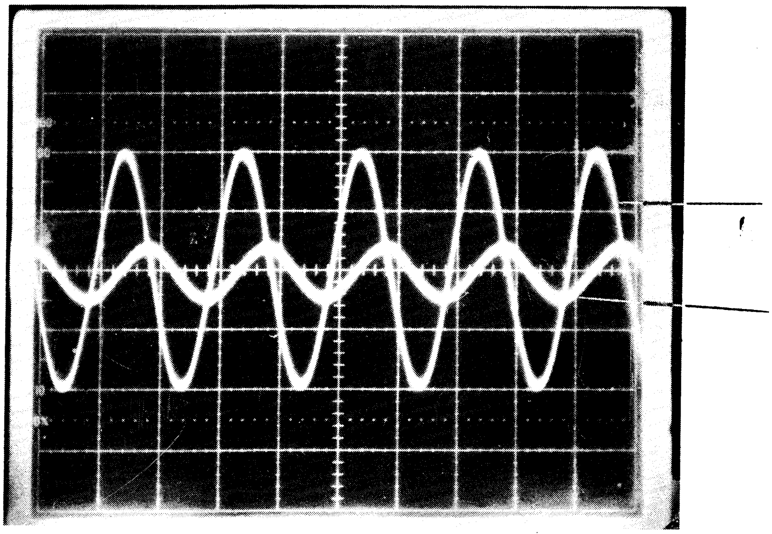


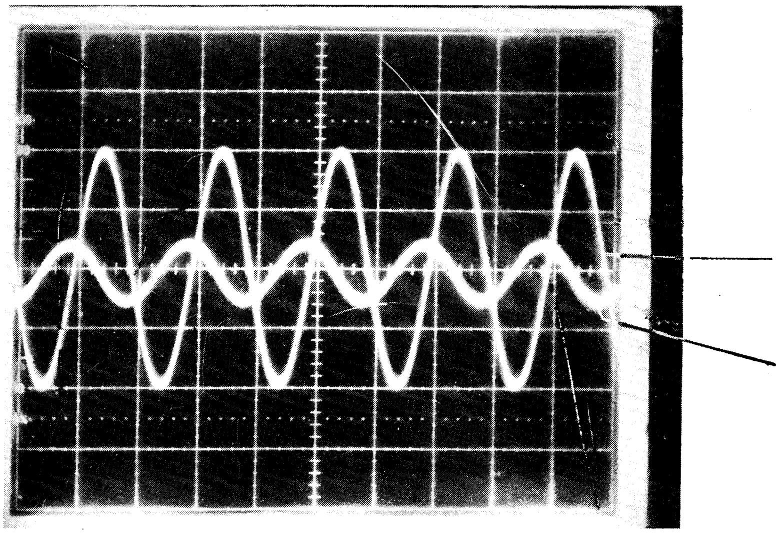
FIG. 3: AC Bridge Schematic



(a) BALANCE CONDITION



(b) OUT-OF-BALANCE CONDITION; OUTPUT LEADS INPUT



(c) OUT-OF-BALANCE CONDITION; OUTPUT LAGS INPUT

Fig. 4: Balance and Unbalance Signals

NOTES

DEMONSTRATION OF TEMPERATURE STABILITY OF "SEND-RECEIVE" METHOD

NO. D4.2

INTRODUCTION: This demonstration illustrates the temperature stability of the "send-receive" eddy current method. A comparison will be made with the "impedance" method.

EQUIPMENT:

1) Eddy current instrument, Defectomat F or equivalent.
2) Combination send-receive/impedance probe, Figure 1.
3) Brass test sample with 1 mm deep EDM notch.

PROCEDURE:

1) Connect FKE leads to corresponding pins of TEST COIL input of Defectomat F eddy current instrument.
2) Set ADAPTION switch to B (impedance bridge mode of operation).
3) Set FREQUENCY to 50 kHz.
4) Select A on TEST COIL range.
5) Balance instrument with probe on test sample.
6) Select SENSITIVITY to yield a vector amplitude of about 6 divisions from the 1 mm deep EDM notch.
7) Set PHASE such that the signal is in the negative X direction as the probe passes over the defect.
8) Remove probe and place sample in a hot water bath.
9) Remove sample after it is heated and place probe onto it. Do NOT rebalance.
10) Observe the instrument monitor for a few moments.
11) Connect EFBK leads to TEST COIL input connector.
12) Set ADAPTION switch to P (send-receive mode of operation).
13) Repeat steps 5 to 10 after the probe has cooled to room temperature.

RESULTS: Observe the large unbalance signal as the probe, when connected in the impedance mode, heats up when in contact with the hot test sample; see Figure 3(a).

Observe that there is no measurable unbalance signal under the same conditions when connected in the send-receive mode.

CONCLUSIONS: The send-receive mode is the better method for absolute measurements in the presence of ambient or sample temperature variations.

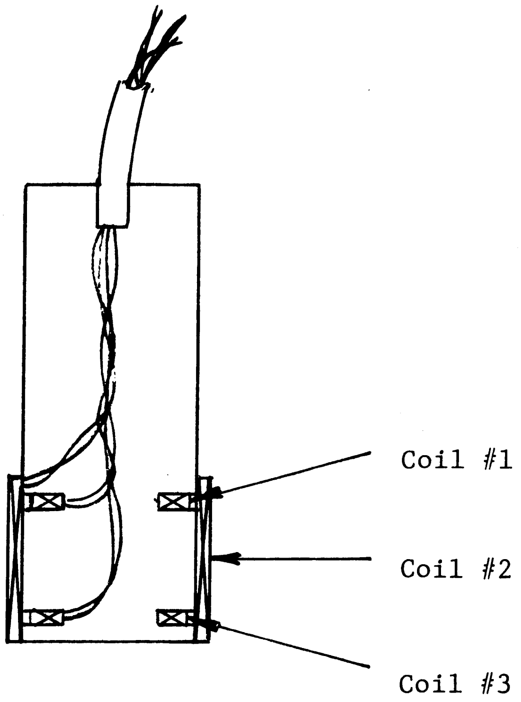
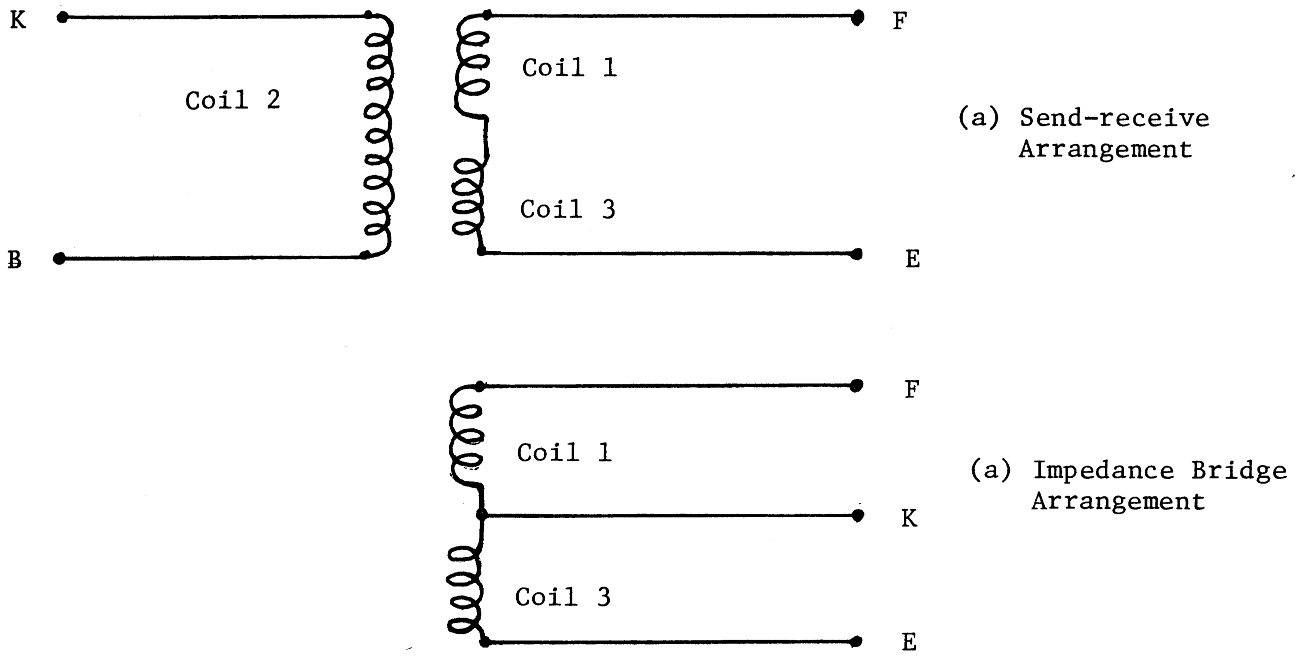


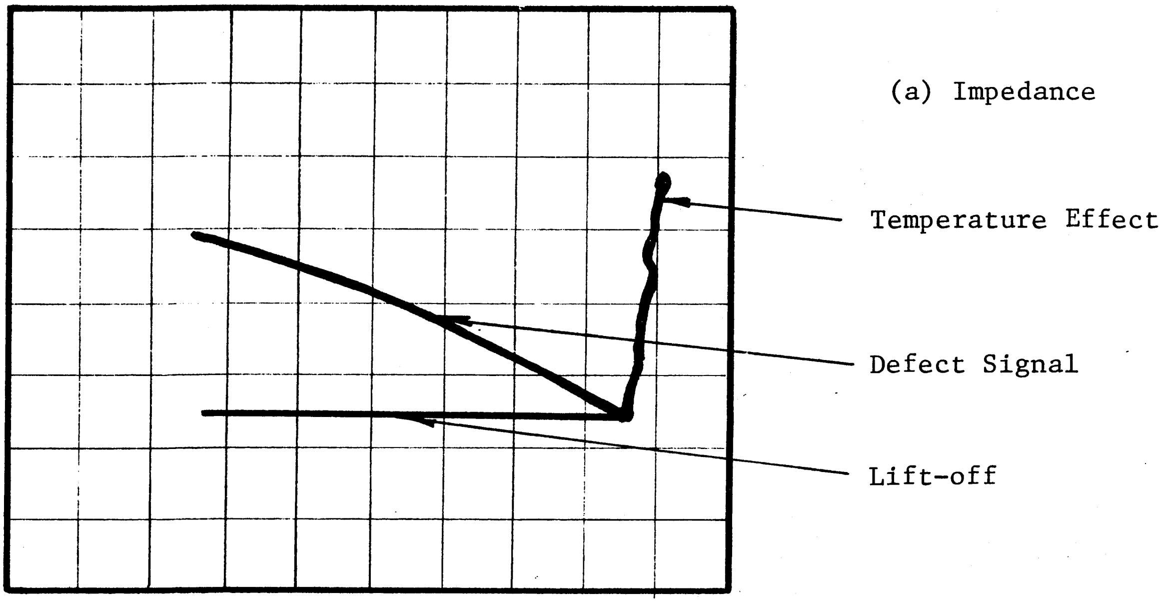
FIGURE 1: Eddy Current Probe



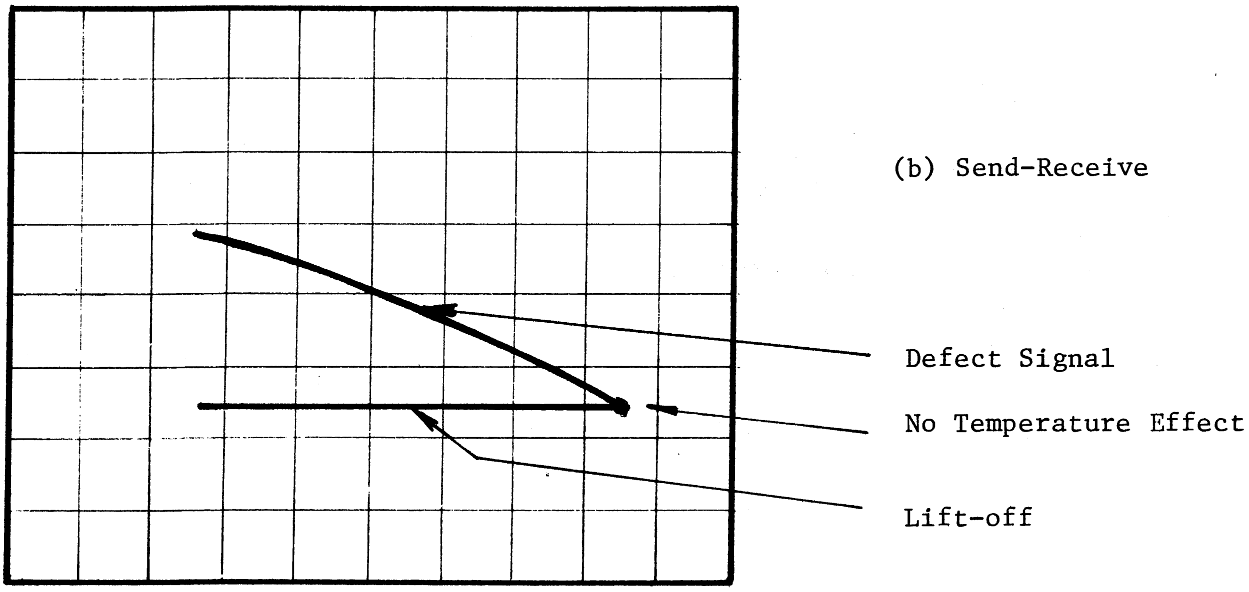
(a) Send-receive Arrangement

(a) Impedance Bridge Arrangement

FIGURE 2: Send-receive and Impedance Probe-coil Connections



(a) Impedance



(b) Send-Receive

FIGURE 3: Signal Response to an Increase in Test Sample Temperature when Probe is Connected in (a) Impedance Mode and (b) Send-Receive Mode

NOTES

SECTION 2 - LABORATORY TESTS

This section contains a description of practical tests which could be used during an eddy current course. They are chosen to give students practice in performing basic inspections using typical instrumentation. Some of these tests, denoted 'experiments' are intended for observation only; whereas others are 'exercises' requiring records from which students must make conclusions.

The tests include: measurement of probe impedance and sample electrical resistivity, determining optimum test frequency for defect detection, estimating actual defect depth in stainless and aluminum samples, and inspecting defective heat exchanger tubes. These tests allow the student to verify some of the theory and information from lectures. The laboratory tests are denoted with a 'L' and numbered to correspond to chapters in "Eddy Current Manual; Test Method, Volume 1".

The results from these tests are available in Volume 2 Supplement "Course Instructors Handbook".

A number of the laboratory exercises described here involve samples containing manufacturing flaws or service-related defects from the CRNL collection. Although these defective samples cannot be exactly duplicated, they are included as an example to follow using suitable substitutes. These exercises are L6.2 to L6.5 for surface probe applications and L8.3 to L8.6 for tube inspections using an internal probe.

Probes are normally specified by a nominal test frequency at which probe impedance will be mid range for most general purpose eddy current instruments. However a wide frequency range can be used without an appreciable decrease in signal to noise ratio.

A general format for tube inspections using internal probes is shown on L8.1. When selecting probes a fill-factor of approximately 0.8 is desirable and absolute probes should be used. However, absolute probes should have an internal reference and they require good guidance. A complete listing of probes used in Section 2 follows. Probes are commercially available from ANDEC* or they can be substituted with equivalent probes from NORTEC** or made from the description given in the listing.

Boeing*** electrical resistivity samples are referenced; they are very accurate, but for most experiments these could be substituted with various metals using tabulated values.

*   ANDEC Manufacturing Ltd., 18 Canso Road, Rexdale, Ontario, M9W 4L8
**   NORTEC Corp., 421 N. Quay, Kennewick, Washington, 99336
*** BOEING Aerospace Company, Seattle, Washington, 98124

SURFACE PROBES

ANDEC NUMBER	DESCRIPTION	APPLICATION
FAR10K.5	12.7 mm coil diameter Nominal frequency = 10 kHz	L3.2, L3.3, L5.1(a), L5.1(b), L5.3, L5.4, L5.5
FAR200K.125	3 mm coil diameter Nominal frequency = 200 kHz	L4.2, L5.1(b), L6.1(a), L6.1(b), L6.3, L6.4 L6.5, L6.7
FAR100K.25	6.2 mm coil diameter Nominal frequency = 100 kHz	L5.2(a), L5.2(b), L6.6
FAR10K.25	6.2 mm coil diameter Nominal frequency = 10 kHz	L5.5, L6.2, L6.5, L6.7
FAR10K1	25 mm coil diameter Nominal frequency = 10 kHz	L5.5
SRF-LF.25	6.2 mm coil diameter Two coils for through transmission Frequency = 2 to 100 kHz	L5.6
SAR200K.125	3 mm coil diameter Magnetic saturation Nominal Frequency = 300 kHz	L6.4
PAR500K.08	2 mm ferrite core Nominal frequency = 500 kHz	L8.1, L8.3, L8.4, L8.5, L8.6

TUBE PROBES

BP625EA	15.9 mm diameter, absolute Frequency = 10 to 50 kHz	L7.1
BP625ED	15.9 mm diameter, differential Frequency = 10 to 50 kHz	L7.1
BP400FA	10.2 mm diameter, absolute Frequency = 150 to 400 kHz	L8.2(a), L8.2(b)

SURFACE PROBES

ANDEC NUMBER	DESCRIPTION	APPLICATION
BP400FD	10.2 mm diameter, differential Frequency = 150 to 400 kHz	L8.1(a), L8.1(b)
BP875BA	22.2 mm diameter, absolute Frequency = 5 to 20 kHz	L8.3
BP875BD	22.2 mm diameter, absolute Frequency = 5 to 20 kHz	L8.3
BP600EA	15.2 mm diameter, absolute Frequency = 75 to 200 kHz	L8.4, L8.5
BP600ED	15.2 mm diameter, differential Frequency = 75 to 200 kHz	L8.4, L8.5
BP525AA	13.3 mm diameter, absolute Frequency = 0.5 to 10 kHz	L8.6
BP525AD	13.3 mm diameter, differential Frequency = 0.5 to 10 kHz	L8.6
BP375DA	9.5 mm diameter, absolute Frequency = 0.5 to 10 kHz	L9.1

SPECIAL PROBES

Encircling coil (Donut probe)	3.2 mm bore, absolute Frequency = 200 kHz to 1 MHz	L8.7(a), L8.7(b)
Encircling coil	3.2 mm bore, differential Frequency = 200 kHz to 1 MHz	L8.7(a), L8.7(b)
Magnetic saturation	9.5 mm diameter, absolute Frequency 0.5 to 10 kHz	L9.1
Magnetic saturation (High-Intensity)	13 mm diameter, differential Frequency = 100 to 500 kHz Magnetic force in tube equivalent to 1.4 x 10^5 ampere turns/meter.	L9.2
Magnetic saturation Low-intensity	13 mm diameter, different Frequency = 100 to 500 kHz Magnetic force in tube equivalent to 0.7 x 10^5 ampere - turns/meter.	L9.2

EDDY CURRENT LABORATORY EXERCISE
No. L3.1

PURPOSE

To measure probe impedance

EQUIPMENT

1) Universal bridge (HP 4260A or equivalent)
2) Assortment of eddy current probes

PROCEDURE

1) Connect probe leads from active coil into terminals of universal bridge (pins B and C of most probe connectors)

TO MEASURE DC RESISTANCE:

1) Set the FUNCTION switch to 'R'.
2) Set the SENSITIVITY switch to Maximum.
3) Set the RANGE switch to 'Ω'.
4) Adjust the CRL dial until the red pointer, at the top centre of the instrument, is in the centre.
5) The digital display at the top right side is the value of the DC resistance in the units displayed above the RANGE switch.

TO MEASURE INDUCTANCE:

7) Set the FUNCTION switch to 'L auto'.
8) Set the RANGE switch to 'mH'.
9) Turn the CLR dial in the direction of the lighted arrowhead above the dial.
10) Continue to turn the dial in that direction until the light of the arrowhead goes out.
11) The inductance is read from the same digital display as was resistance in the units displayed above the RANGE switch.
12) The same procedure can be carried out for D and C leads (other coil) of the probe.

TO CALCULATE IMPEDANCE:

Magnitude of Impedance:

$$|Z| = \sqrt{R^2 + X_L{}^2}$$

Angle of Impedance:

$$\Theta = \text{Arctan } \frac{X_L}{R}$$

Where Z is impedance in ohms (Ω)
R is DC resistance in ohms (Ω)
X is inductive reactance in ohms (Ω)
f is frequency in hertz (Hz). (HP 4260A has a fixed frequency of 1000 hertz.)
L is inductance in henries (H)
Θ is phase angle in degrees(°)

NOTES

EDDY CURRENT LABORATORY EXERCISE
No. L3.2

PURPOSE

To plot the impedance curve for varying test frequency using probe impedance values obtained with a Vector Impedance Meter.

EQUIPMENT

Vector Impedance Meter: HP4800A or equivalent.
Absolute surface probe: ANDEC FAR10K.5 or equivalent.

TEST AND CALIBRATION SAMPLE

Brass plate, 5 mm thick or thicker.

PROCEDURE

1. Connect the probe active coil to the input connector of the vector impedance bridge.
2. Select a frequency of 2 kHz.
3. With probe in air, adjust the $|Z|$ RANGE switch until the Z MAGNITUDE meter indicates a reading.
4. Read and record the impedance from Z MAGNITUDE meter.
5. Record the phase angle from PHASE ANGLE meter.
6. Repeat for frequencies of 5, 10, 20 and 50 kHz.
7. Measure the impedance at 100 Hz to obtain the value of R_{DC}, (at this frequency the impedance will be predominately resistive).
8. Repeat steps 2,3,4,5 and 6 with probe adjacent to brass plate.

Calculate $\omega L/\omega L_o$ and $R_L/\omega L_o$.

where ωL is inductive reactance of probe coupled to the sample = $|Z| \sin \Theta$
ωL_c is inductive reactance of probe in air

and R is resistive component of reactance when coupled to the sample
$= |Z| \cos \Theta - R_{DC}$

where R is resistance of coil and cable = Z_o at $f = 100$ Hz

RECORD

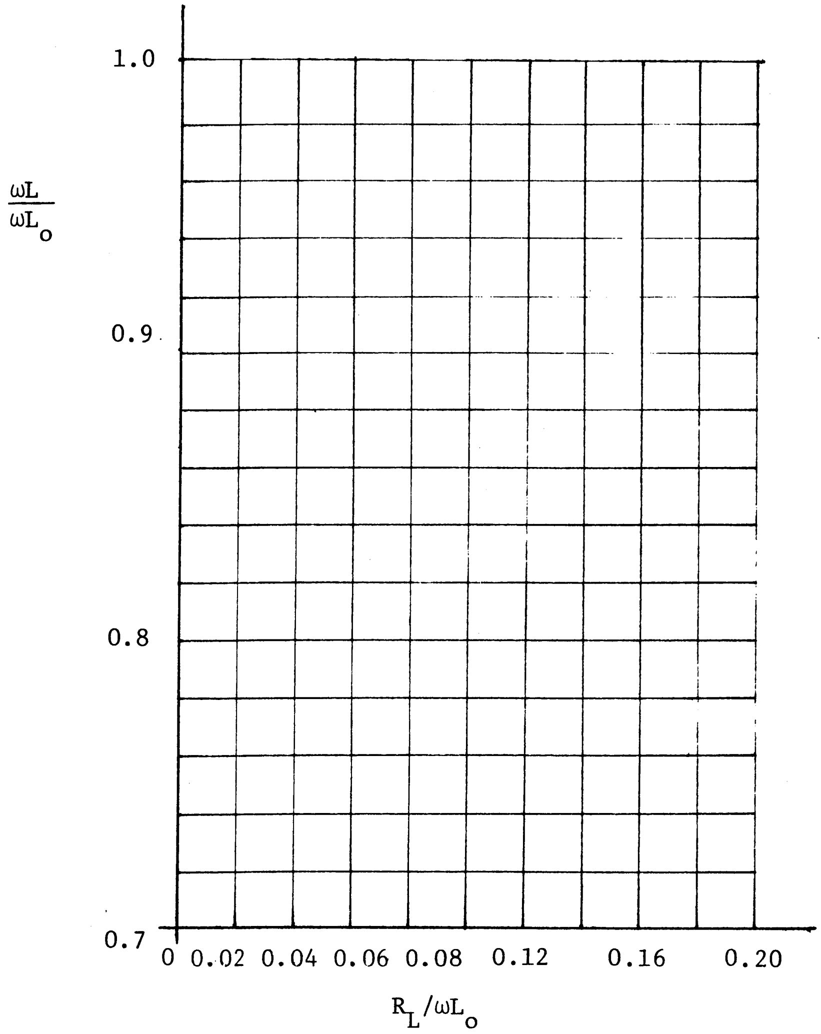
Plot $\omega L/\omega L_o$ on Y-axis against $R_L/\omega L_o$ on X-axis on reverse side of page.

RESULTS

Note how test frequency affects normalized probe impedance.

IMPEDANCE CURVE FOR A SURFACE PROBE WITH VARYING FREQUENCY

	PROBE IN AIR			PROBE ON BRASS				NORMALIZED	
FREQ.	Z_o	Θ_o	ωL_o	Z	Θ	ωL	R_L	$\omega L/\omega L_o$	$R_L/\omega L_o$
kHz	Ω	deg.	Ω	Ω	deg.	Ω	Ω		



R_{DC} =

$\omega L = Z \sin \Theta$

$R_L = Z \cos\Theta - R_{DC}$

EDDY CURRENT LABORATORY EXERCISE
No. L3.3

PURPOSE

To plot the impedance curve for varying sample resistivity using probe impedance values obtained with a Vector Impedance Meter.

EQUIPMENT

Vector Impedance Meter: HP4800A or equivalent.
Absolute surface probe: ANDEC FAR10K.5 or equivalent.

TEST AND CALIBRATION SAMPLES

Copper, brass, aluminum bronze, lead, zirconium or titanium, and Inconel 600 samples. (Refer to table 9.1, "EDDY CURRENT MANUAL Volume 1", for electrical resistivity values).

PROCEDURE

1. Connect the probe active coil to the input connector on the vector impedance bridge. (Pins B and C of most probes).
2. Select a frequency of 10 kHz.
3. With probe in air adjust the $|Z|$ RANGE switch until the Z MAGNITUDE meter indicates a reading.
4. Read and record the impedance from Z MAGNITUDE meter.
5. Record the phase angle from the PHASE ANGLE meter.
6. Measure the impedance at 100 Hz to obtain the value of R_{DC}.
7. Repeat steps 2,3,4 and 5 with probe adjacent to each sample in turn.

Calculate $\omega L/\omega L_o$ and $R_L/\omega L_o$.

where ωL is inductive reactance of probe coupled to the sample = $|Z| \sin \Theta$
ωL_o is inductive reactance of probe in air

and R is resistive component of reactance when coupled to the sample
$= |Z| \cos \Theta - R_{DC}$

where R is resistance of coil and cable = Z_o at f = 100 Hz

RECORD

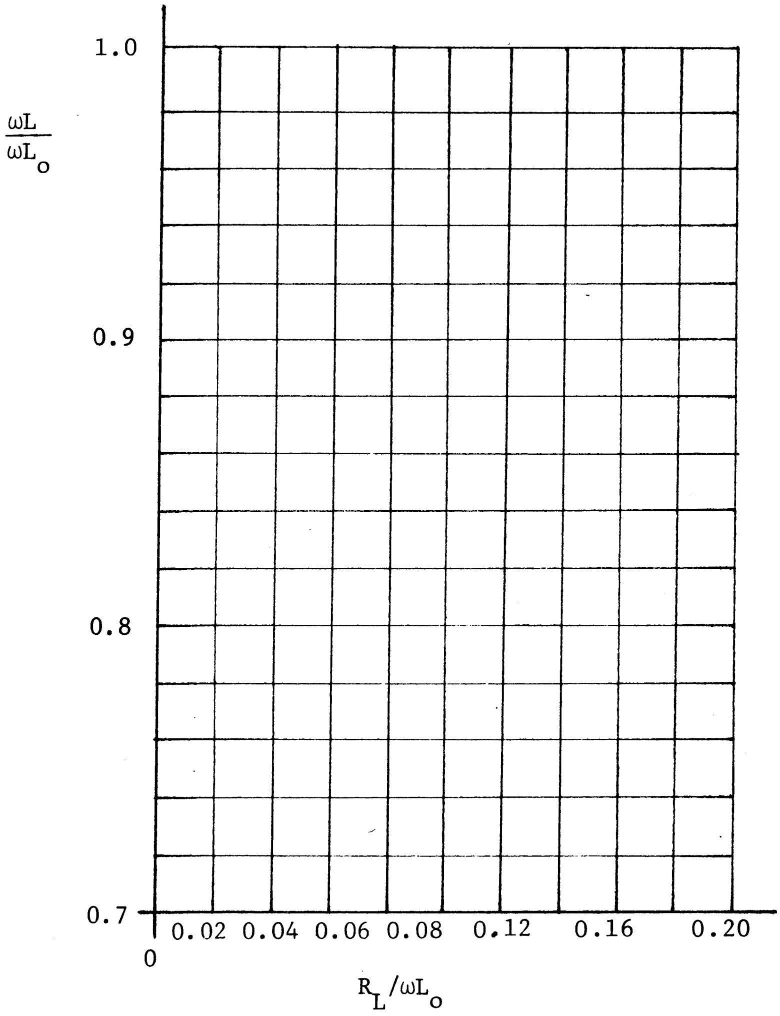
Plot $\omega L/\omega L_o$ on Y-axis against $R_L/\omega L_o$ on X-axis on reverse side of page.

RESULTS

Note how a change in sample resistivity affects normalized probe impedance.

IMPEDANCE CURVE FOR A SURFACE PROBE WITH VARYING RESISTIVITY SAMPLES

MATERIAL	Z	Θ	ωL	R_L	$\omega L/\omega L_o$	$R_L/\omega L_o$
AIR						
INC. 600						
Zr-Nb						
LEAD						
AL. BRONZE						
BRASS						
COPPER						



R_{DC} =

$\omega L = Z \sin \Theta$

$R_L = Z \cos \Theta - R_{DC}$

EDDY CURRENT LABORATORY EXPERIMENT
No. L4.1

PURPOSE

Familiarization with a general purpose eddy current instrument.

EQUIPMENT

Eddy Current Instrument: Automation Industries EM3300 or equivalent
Eddy Current probe: any differential or absolute probe with internal reference
Tube: any tube suitable for use with above probe.

PROCEDURE

1) Turn on instrument.
2) Push in the four store buttons on the top right hand corner of the storage monitor.
3) Connect probe to instrument and place probe in tube.
4) Adjust FREQUENCY control to designated test frequency of probe.
5) Adjust the VERTICAL and HORIZONTAL black knobs to the desired voltage settings, usually 2 VOLTS/DIV.
6) Set SENSITIVITY to zero.
7) Set INTENSITY knob to about the middle position.
8) If dot is not on the screen, push (and hold) in the BEAM-FINDER and adjust the red VERTICAL and HORIZONTAL knobs to bring the dot on screen.
9) Turn the PHASE knob to trace out a circle.
10) Adjust the red VERTICAL and HORIZONTAL knobs to roughly centralize the circle on the screen.
11) Increase SENSITIVITY to approximately 25%.
12) Set switch on bottom right hand corner in the 'L' position. At this position the probe will normally balance automatically when the AUTO BALANCE button is pressed. (The 'C' position is for a test frequency above probe-cable resonance; a condition rarely experienced).
13) If automatic balance does not bring dot back on screen after a few seconds, decrease sensitivity setting and try again. If it does balance increase sensitivity slowly keeping the AUTO BALANCE button pressed.
14) If the instrument does not balance automatically, try balancing manually at a low sensitivity where the dot is on screen. Adjust the X and R BALANCE knobs until the dot is close to the centre of the screen. Increase sensitivity and repeat.
15) If instrument does not balance, try lowering test frequency or change probe.
16) When using an absolute bobbin type probe, set PHASE to give a horizontal signal moving to the left as the probe passes an internal defect. When using a surface type probe set phase such that the lift-off signal is horizontal and moves to the left as the probe is lifted from the sample.

NOTES

EDDY CURRENT LABORATORY EXPERIMENT
No. L4.2

PURPOSE

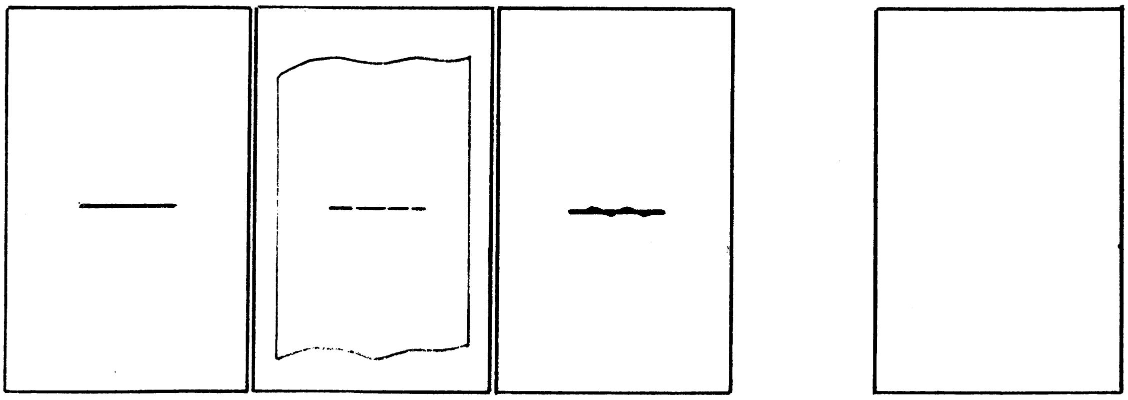
To compare the effectiveness of a crack detector, a conductivity meter, and a general purpose eddy current instrument, for plate inspection.

EQUIPMENT

Eddy Current Instrument: EM3300 or equivalent.
Crack detector: Magnaflux ED-250 or equivalent.
Conductivity meter: Verimet M4900A or equivalent.
Eddy current probes: Probes supplied with the crack detector and conductivity meter, and ANDEC FAR200K.125 or equivalent for the general purpose instrument.

TEST AND CALIBRATION SAMPLES

Two aluminum flat plates of different grades, about 6 mm thick, one with an EDM notch and one plain.



(a)
EDM notch
0.5 mm deep
12 mm long

(b)
Aluminum
foil over
notch

(c)
Ferromagnetic
strand in
notch

(d)

$\rho = 5.4\ \mu\Omega\text{-cm}$

$\rho = 4.1\ \mu\Omega\text{-cm}$

PROCEDURE

Set up the special purpose instruments according to the user's manual. They are normally set up to compensate for lift-off variations. With the crack detector and conductivity meter, scan across the 0.5 mm deep x 12 mm long EDM notch (a) by itself, (b) when covered with a layer of aluminum foil and (c) with a strand of steel wool placed in the EDM groove and (d) take a reading with the probe touching the other slightly higher resistivity sample without changing settings. When using the EM3300 and ANDEC probe, repeat the above at test frequencies of 50, 200 and 500 kHz.

RECORD

Record the readings from the crack detector and conductivity meter on Table 1. When using the EM3300, sketch on the reverse side of page the X-Y signal images as seen on the storage monitor.

CONCLUSIONS

The crack detector and conductivity meter gave eddy current indications for all of the tests (a) to (d). The crack detector gave different readings for the same 'crack depth' and a defect indication for the higher resistivity sample. The conductivity meter gave different 'conductivity' values for the same conductivity sample in the presence of other anomalies. With the general purpose instrument it was possible, through pattern recognition, to distinguish between the surface and subsurface (under layer of aluminum) defects, electrical resistivity, and ferromagnetic false indications. The depth of the defect could be estimated by retesting at various test frequencies and comparing the signals to those from known calibration defects.

In conclusion, the crack detector and conductivity meter could not distinguish between actual defects, or conductivity variations, and false indications. Whereas the signals from the general purpose instrument could be analyzed through pattern recognition.

TABLE 1 - EDDY CURRENT RESULTS

	CRACK DETECTOR READING	CONDUCTIVITY METER READING
DEFECT FREE AREA		
SURFACE CRACK: (a) 0.5 mm deep x 12.7 mm long		
SUBSURFACE CRACK: (b) 0.5 mm deep x 12.7 mm long under Aluminum foil		
Ferromagnetic Inclusion (c)		
Resistivity Change (d)		

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT
No. L5.1(a)

PROBLEM

To observe the effect of different resistivity samples on coil impedance.

EQUIPMENT

Eddy Current Instrument: Automation Industries EM3300 or equivalent.
Absolute surface probe: ANDEC FAR10K.5 or equivalent.

TEST SAMPLES

Calibration samples: Ferrite, carbon steel and Boeing calibration set containing copper (1.7 μΩ-cm), pure aluminum (2.8 μΩ-cm) aluminum alloys (4.1 and 4.9 μΩ-cm), brass (6.4 μΩ-cm) phosphor bronze (9.9 μΩ-cm), everdure bronze (24.7 μΩ-cm), and titanium alloy (164.5 μΩ-cm) or a calibration standard described in Figure 6.9 of "Eddy Current Manual, Volume 1".

PROCEDURE

At a test frequency of 10 kHz, set HORIZONTAL & VERTICAL display at 2 VOLTS/DIV. and balance the instrument with the probe in air. Set PHASE such that the eddy current signal moves upwards as the probe approaches the ferrite sample. Set SENSITIVITY to keep the signals on screen when the probe is in contact with each Boeing resistivity sample. Place probe on each sample, noting the sample's resistivity. Check that signals on storage monitor resemble those in Figure 5.1(a) on reverse side of page. Repeat at 100 kHz test frequency.

OBSERVATION

Observe the direction and behaviour of the various signals e.g. lift-off, higher/lower conductivity, ferrous/nonferrous materials. Note the resemblance of the signals in Figure 5.1(a) to coil impedance/voltage graphs Figure 5.9 to 5.12 in the "Eddy Current Manual", Volume I.

Compare resistivity curve with L3.3.

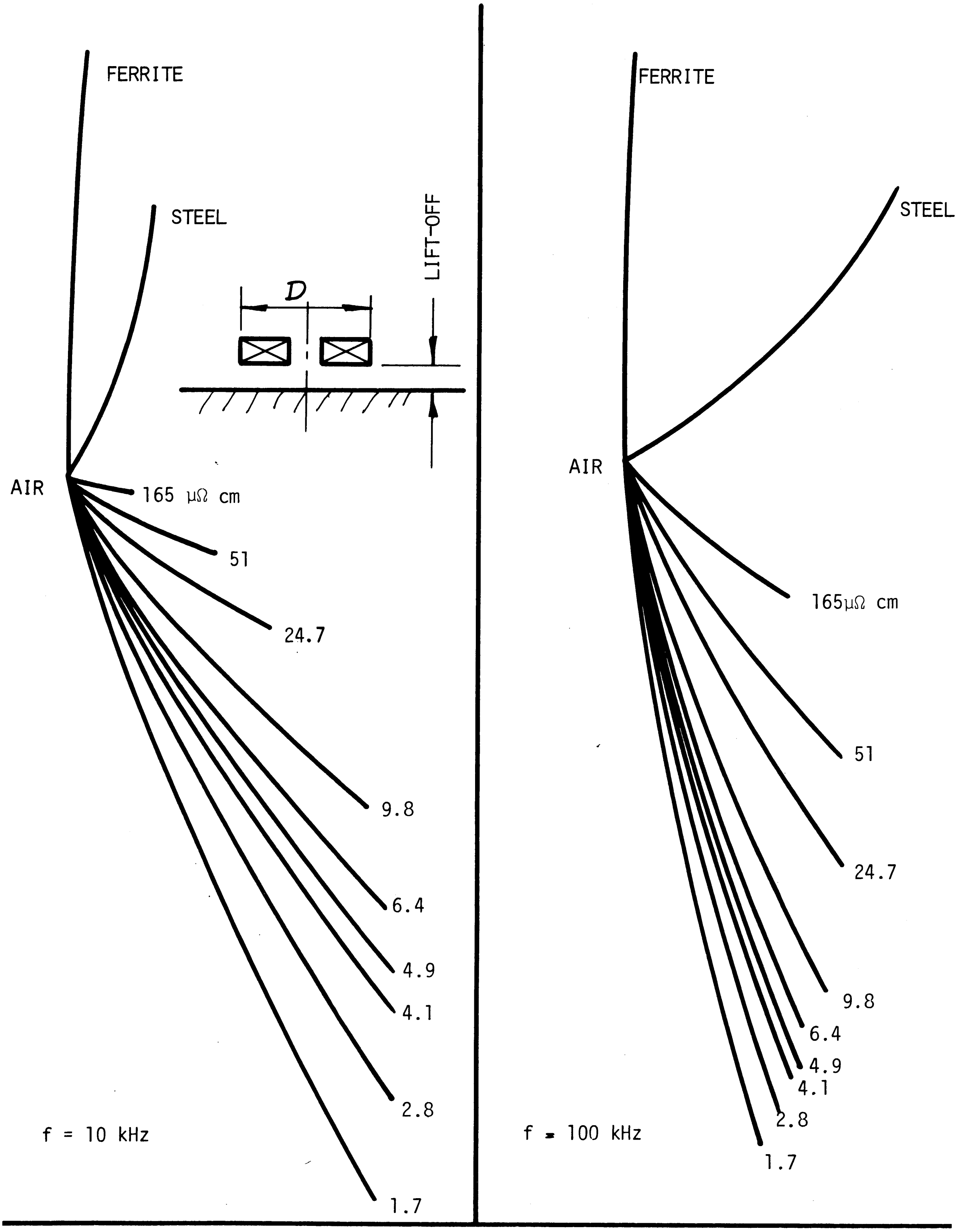


FIGURE 5.1(a) COIL IMPEDANCE/VOLTAGE GRAPH DISPLAY
Probe: Nortec SP10B (10 mm Diameter)

EDDY CURRENT LABORATORY EXERCISE
No. L5.1(b)

PURPOSE

To estimate electrical resistivity of unknown test samples

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.

Absolute surface probe: ANDEC FAR10K.5 and FAR200K.125 or equivalent.

TEST AND CALIBRATION SAMPLES

Test Samples: 4 unknown non-ferromagnetic samples; for selection see Table 9.1 of "Eddy Current Manual", Volume 1.

Calibration samples: Ferrite sample and Boeing calibration set containing copper (1.7 μΩ-cm), pure aluminum (2.8 μΩ-cm) aluminum alloys (4.1 and 4.9 μΩ-cm), brass (6.4 μΩ-cm), phosphor bronze (9.9 μΩ-cm), everdure bronze (24.7 μΩ-cm), titanium alloy (164.5 μΩ-cm), or a Calibration Standard described in Figure 6.9 of 'Eddy Current Manual' Volume 1.

PROCEDURE

At test frequencies, 10 kHz, 100 kHz, and higher if necessary, balance instrument with probe in air. Set PHASE so the eddy current signal moves straight upwards as the probe approaches a ferrite sample. Set SENSITIVITY to keep all signals on screen when the probe is in contact with each resistivity sample. Make probe contact with all the samples, including the four unknowns.

RECORDS

Sketch on the reverse side of the page the X-Y signal images seen on the storage monitor. Superimpose the signals from the unknown samples on Fig. 5.1(b).

RESULTS

The electrical resistivity of the unknown samples can be estimated by interpolating between the values of the known samples.

Fill in the resistivity values of sample: A = ______________
B = ______________
C = ______________
D = ______________

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L5.4

PURPOSE

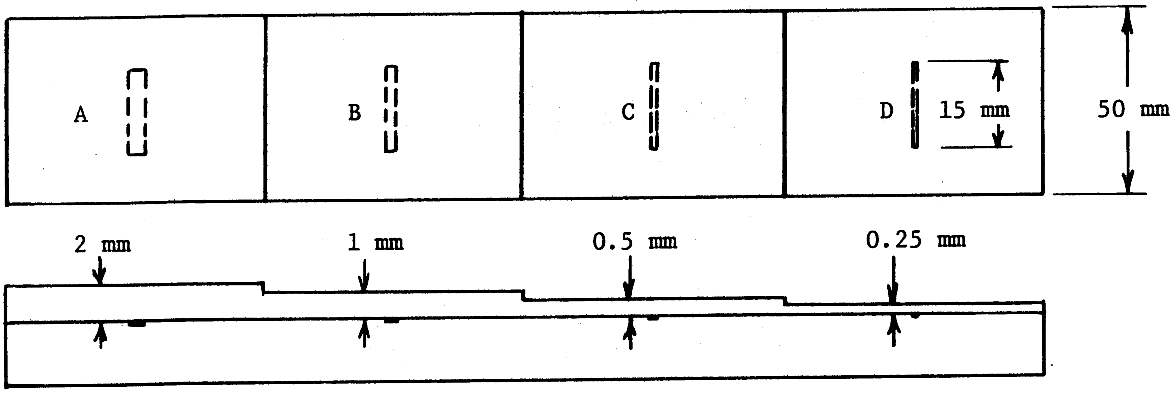
To observe the change in the eddy current signals with: (a) depth and (b) frequency, for various subsurface defects.

EQUIPMENT

Eddy current instrument:	Automation Industries EM3300 or equivalent.
Absolute surface probe:	ANDEC FAR10K.5 or equivalent.

TEST AND CALIBRATION SAMPLE

Brass step plate containing subsurface notches.



PROCEDURE

Experiment with test frequencies from 10 kHz through 50 kHz until an approximate 90° phase separation between signals from lift-off and subsurface defect C is achieved. Set PHASE such that the lift-off signal is in the negative X direction as the probe is lifted from the sample. Set SENSITIVITY to produce signal amplitudes of 2 to 4 volts for defects. At this frequency observe the results from subsurface defects A, B, C & D.

RECORD

Sketch on the reverse side of page the signals for lift-off and defects.

RESULTS

From above tests calculate ratio t/δ for 90° separation between lift-off and defect signal C ($t=0.5$ mm). Use $\rho = 6.5\ \mu\Omega$- cm.

OBSERVATIONS

Compare the signals as probe is moved over defects B and C; note that the angle, relative to lift-off, is double. This is expected since depth is double and therefore phase lag to the defect has doubled. Similarly, compare the signals from defects C and D.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L5.5

PURPOSE

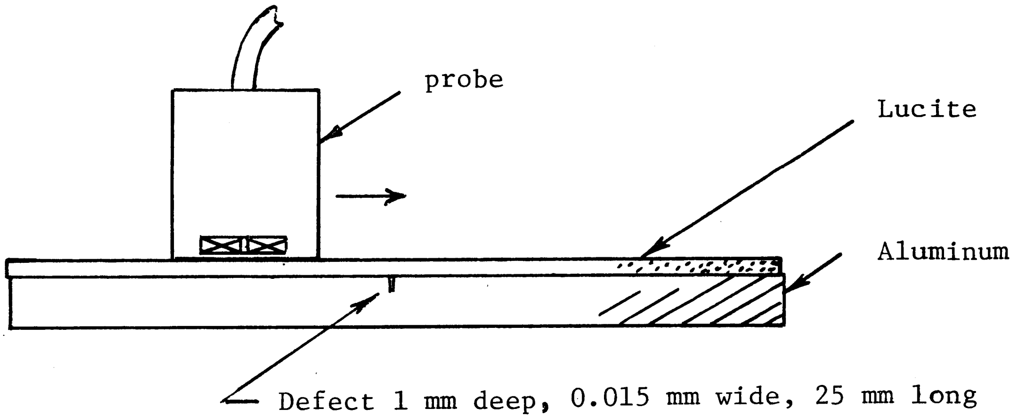
To demonstrate decrease in sensitivity with increasing lift-off distance, for various probe diameters.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Surface probes: ANDEC FAR10K1 or equivalent.
ANDEC FAR10K.5 or equivalent.
ANDEC FAR10K.25 or equivalent.

TEST AND CALIBRATION SAMPLE

Two lucite plates; 10 cm x 5 cm, 1 mm thick and 2 mm thick.
Aluminum AISI 5054 plate, 10 cm x 5 cm x 6 mm thick with EDM notch as shown.



PROCEDURES

Calculate test frequency so that one standard depth of penetration is 1 mm; use ρ = 5 $\mu\Omega$-cm. Balance instrument with 25 mm probe on sample, set PHASE such that the lift-off signal is in the negative X direction as the probe is lifted from the sample and set SENSITIVITY to yield a signal of approximately 10 volts for the defect. Pass probe over defect when (a) coupled directly to the plate, (b) when spaced off by 1 mm lucite, (c) when spaced off by 2 mm lucite.
Repeat using the other two probes.

RECORD

Sketch on the reverse side of the page the X-Y signal images.

RESULTS

Compare the drastic decrease in defect signal amplitude with probe-to-sample spacing. Calculate the ratio of signal amplitudes for i) smallest probe and ii) largest probe as follows:

$$\frac{\text{V, spaced off 2 mm}}{\text{V. directly coupled}} = \text{i) \_\_\_\_\_\_\_\_, ii) \_\_\_\_\_\_\_\_.}$$

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L6.1(a)

PURPOSE

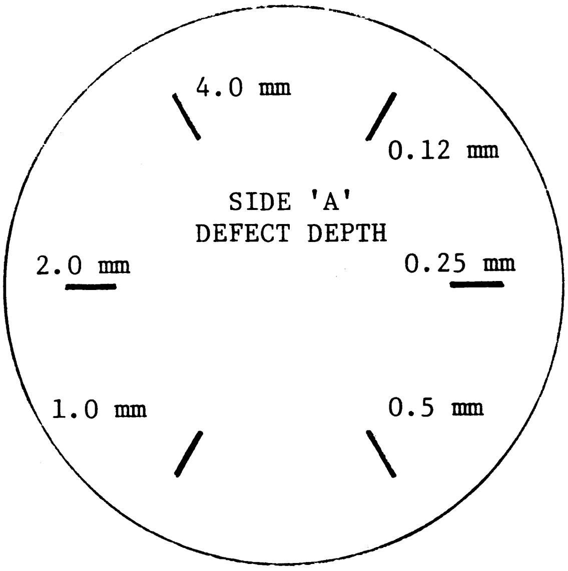
To observe how signal phase and amplitude, from a surface defect, change with defect depth and length, at constant frequency.

EQUIPMENT

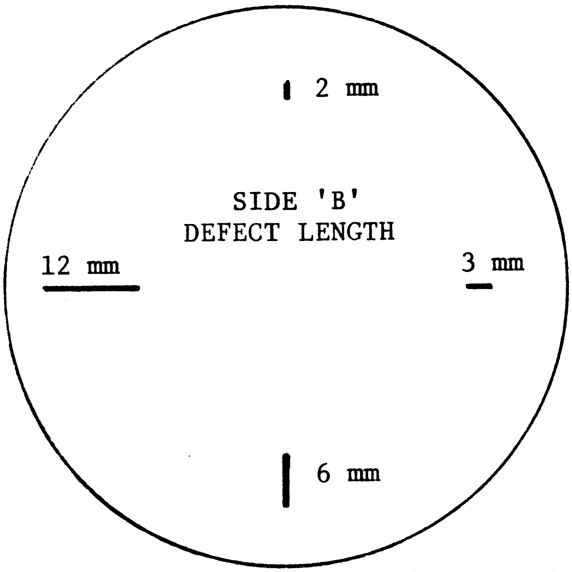
Eddy current instrument:	Automation Industries EM3300 or equivalent.
Absolute surface probe:	ANDEC FAR200K.125 or equivalent.

TEST AND CALIBRATION SAMPLE

Zirconium alloy (Zr2) 8 cm diameter x 1.5 cm thick.



EDM notches 6 mm long and 0.15 mm wide



EDM notches 0.5 mm deep and 0.15 mm wide

PROCEDURE

Select 300 kHz test frequency. Adjust SENSITIVITY to produce a signal amplitude of about 10 volts for the 4 mm deep x 6 mm long defect. Set PHASE such that lift-off signal is in the negative X direction as the probe is lifted from the sample. Scan all defects on Side A and then Side B.

RECORD

Sketch on reverse side of page the signal images as seen on the storage monitor.

RESULTS

Write your observation on the reverse side stating how surface defect signal phase and amplitude change with defect depth and length.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
NO. L6.4

PURPOSE

To estimate depth of manufacturing surface defects in an Inconel 600 thick-wall tube sample. This test uses a sample, containing a manufacturing flaw, from the CRNL collection.

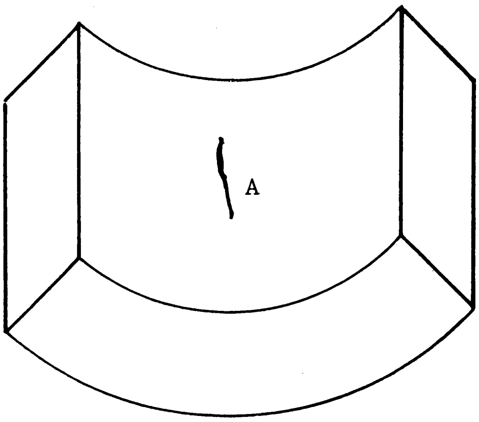
EQUIPMENT

Eddy current instrument:	Automation Industries EM3300 or equivalent.
Absolute surface probe:	ANDEC FAR200K.125 (regular probe) and SAR200K.125 (saturation probe).

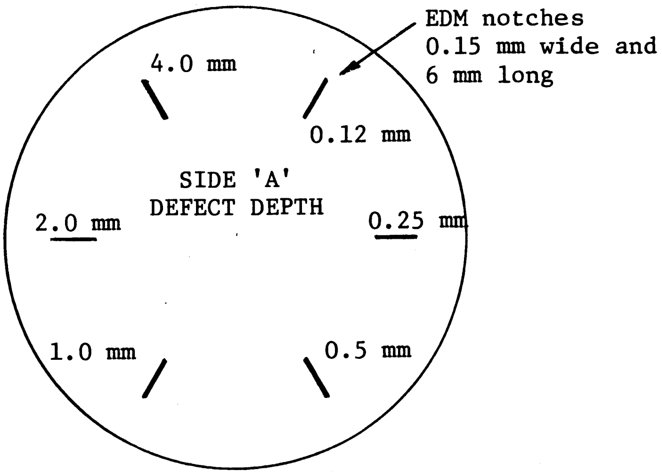
Small high intensity magnet.

TEST AND CALIBRATION SAMPLE

Test sample: Section of Inconel 600 extrusion hollow containing a manufacturing flaw. (CRNL test sample 6.4).
Calibration sample: Plate of similar electrical resistivity with EDM notches.



Test Sample



Calibration Sample

PROCEDURE

At a frequency of 100 kHz, balance instrument with probe on sample and set PHASE such that the lift-off signal is in the negative X direction as the probe is lifted from the sample. Set SENSITIVITY to produce a signal amplitude of 5 volts for a 1 mm deep defect. Estimate defect depth by interpolating from calibration defect signals. Repeat at 300 kHz and 1 MHz. Repeat with saturation probe at same three test frequencies. Using the magnet, compare the magnetic attraction of this sample to other metals.

RECORD

Sketch on reverse side of page the defect signal images seen on the storage monitor.

RESULTS

Estimated defect depth ______ mm.
As the frequency was lowered how did the defect signal change relative to lift-off signal using (a) conventional probe and (b) saturation probe?
Would this metal be classed as nonferromagnetic, mildly ferromagnetic, or strongly ferromagnetic?

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L6.5

PURPOSE

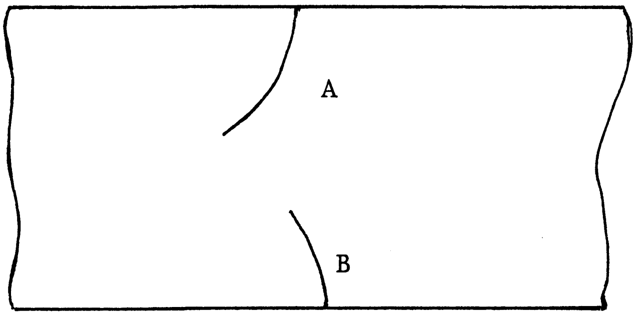
To inspect for surface cracks in a tool steel plate. This test uses a sample, containing quench cracks, from the CRNL collection.

EQUIPMENT

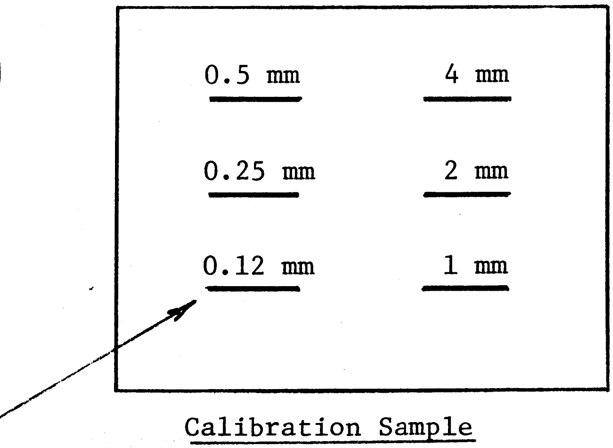
Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute surface probes: ANDEC FAR200K.125 and FAR10K.25 or equivalent.
Small magnet

TEST AND CALIBRATION SAMPLES

Test sample: Tool steel bar, 5 cm x 20 cm x 1.2 cm thick, containing deep cracks propagated from each side.
Calibration sample: Carbon steel flat bar, 10 cm x 10 cm x 1.2 cm thick, containing EDM notches as shown.



Test Sample



EDM notches
0.15 mm wide and 10 mm long

Calibration Sample

PROCEDURE

For test frequencies 20 kHz, 100 kHz and 1 MHz (and using appropriate probe) balance instrument with probe on calibration sample and set phase such that the lift-off signal is in the negative X direction as the probe is lifted from the sample. Select a suitable sensitivity. Observe the signal images from defects A&B and the signals from material noise. Compare with those of calibration sample.

RECORD

Sketch on the reverse side of page the X-Y signal images seen on the storage monitor.

RESULTS

How did the material noise and defect signals change in phase relative to lift-off with frequency? How did the eddy current signal change with calibration defect depth?
What material property variations caused the "material noise" signals?

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L6.6

PURPOSE

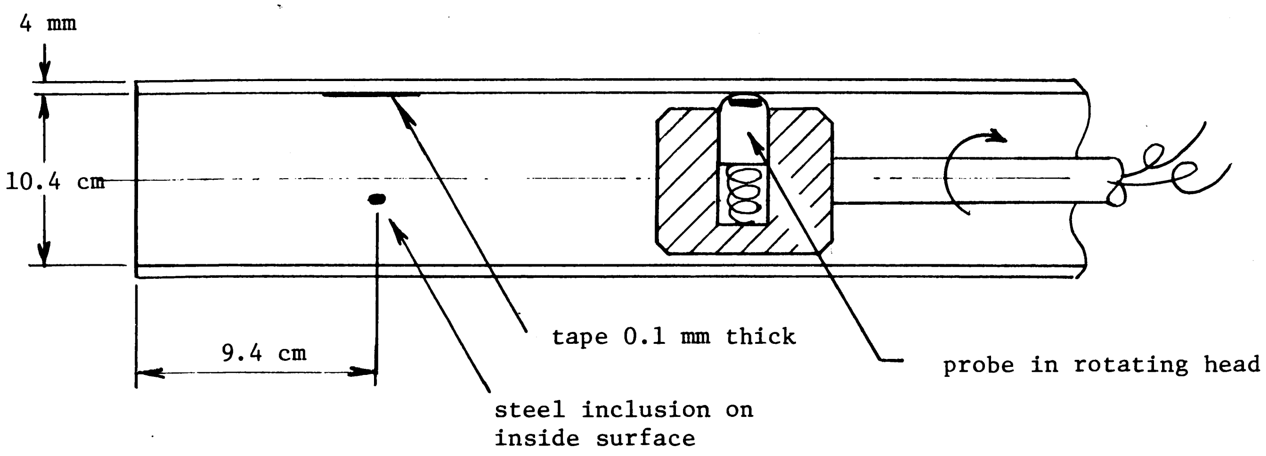
To distinguish between ferromagnetic indications and flaws. This test uses a sample, from the CRNL collection, containing a ferromagnetic inclusion embedded during the manufacturing process.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute surface probe: ANDEC FAR100K.25 or equivalent probe held in contact with tube by spring force.

TEST SAMPLE

Zirconium alloy tube, 10.4 cm I.D., with a ferromagnetic steel chip (0.01 mm^3) embedded into the inside surface (CRNL test sample P660).



PROCEDURE

Calculate test frequency to make one standard depth of penetration equal to 1 mm; use $\rho = 53\ \mu\Omega$-cm. Balance the instrument with probe against tube wall. Set PHASE such that the lift-off signal is in the negative X direction as the probe is lifted from the tube. Set SENSITIVITY to give 1 volt for the 0.1 mm lift-off. Repeat previous procedure using 1/10 the frequency noting phase angle change with the change in frequency.

RECORD

Sketch on the reverse side of page the signal images as seen on storage monitor.

OBSERVATIONS

Note that the angle between the ferromagnetic signal and lift-off signal increases with decreasing test frequency. Consider this angle on the impedance diagram at the two operating points, see page 99 of Eddy Current Manual, Vol. 1.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT
No. L6.7

PURPOSE

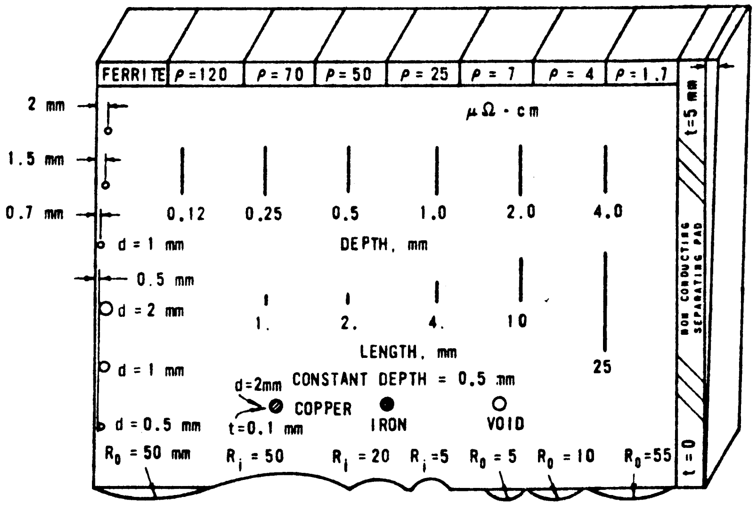
To inspect a component and identify any signal sources. If the signals are due to defects, determine depth of penetration. This is a general exercise to introduce the student to a calibration standard.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute surface probe: choice of ANDEC FAR10K.5 FAR10K.25, FAR200K.125 or equivalent.

TEST AND CALIBRATION SAMPLE

Test sample: Any defective non-ferromagnetic sample with electrical resistivity approximately equal to the calibration standard.
Calibration sample: Calibration standard described in Figure 6.9 of 'Eddy Current Manual' Vol. 1.



PROCEDURE

Calculate test frequency to make one standard depth of penetration equal to 1 mm. Balance instrument with probe on calibration sample and set phase such that the lift-off signal is in the negative X direction as the probe is lifted from the material. Set sensitivity to produce a signal amplitude of about 10 volts for the 1 mm deep calibration defect. Use a lower and higher frequency, if required, to differentiate between signal sources and to estimate defect depth more accurately.

RECORD

Sketch, on the reverse side of page, the defect signal images as seen on the storage monitor.

RESULTS

Identify signal source; if it is a defect state its depth.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT
No. L7.1

PURPOSE

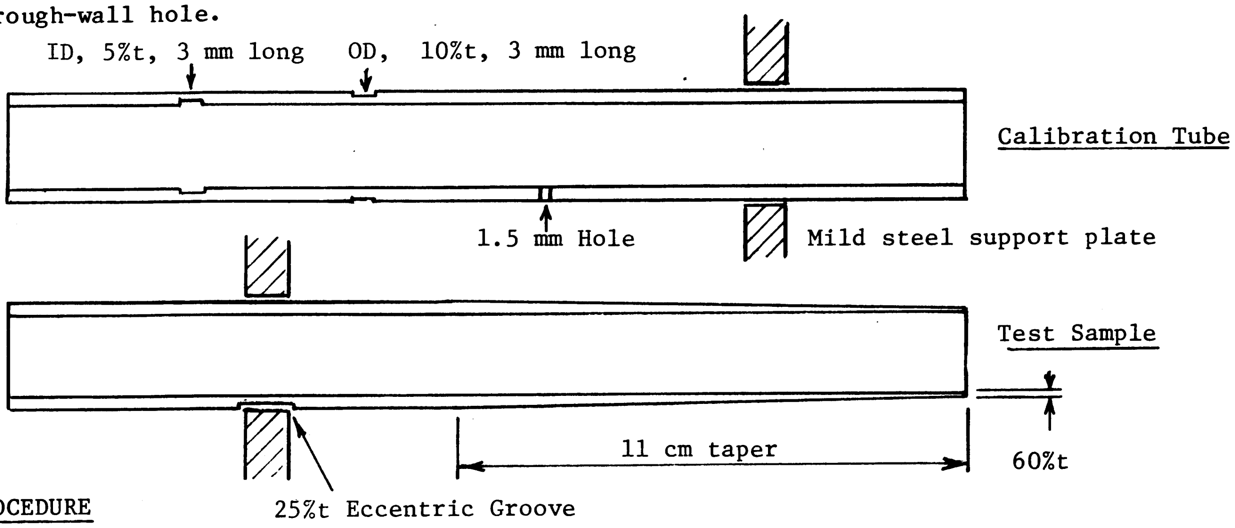
To compare differential and absolute probes for heat exchanger tube testing.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP625EA or equivalent.
Differential probe: ANDEC BP625ED or equivalent.
Two-channel strip chart recorder: HP7402A or equivalent.

TEST AND CALIBRATION SAMPLES

Test sample: 304 stainless steel tube 19 mm O.D., 1.1 mm wall thickness (t), with an eccentric groove (simulated support fretting) and gradual wall thinning (simulated erosion/corrosion).
Calibration sample: similar tube with an outside groove, an inside groove, and a through-wall hole.



PROCEDURE

At the test frequency f_{90} (page 124 of Eddy Current Manual, Vol. 1), balance the instrument with the differential probe inside tube. Set phase so the ID defect traces a signal in the negative X direction first as the probe is retracted. Set SENSITIVITY so that a 1.5 mm through- wall hole yields a signal of 2 volts vector amplitude, and scan tube length. Repeat with absolute probe.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor. Also record the X and Y components of signals on the strip chart recorder.

OBSERVATIONS

The tube taper was not reliably located with the differential probe, whereas it was readily located with the absolute probe. Also observe the complex differential probe signal for a defect under a support plate; the signal cannot be reliably deciphered. Whereas the absolute probe signal can be analyzed as an external defect under the support plate.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. 8.1
GENERAL FORMAT

PURPOSE

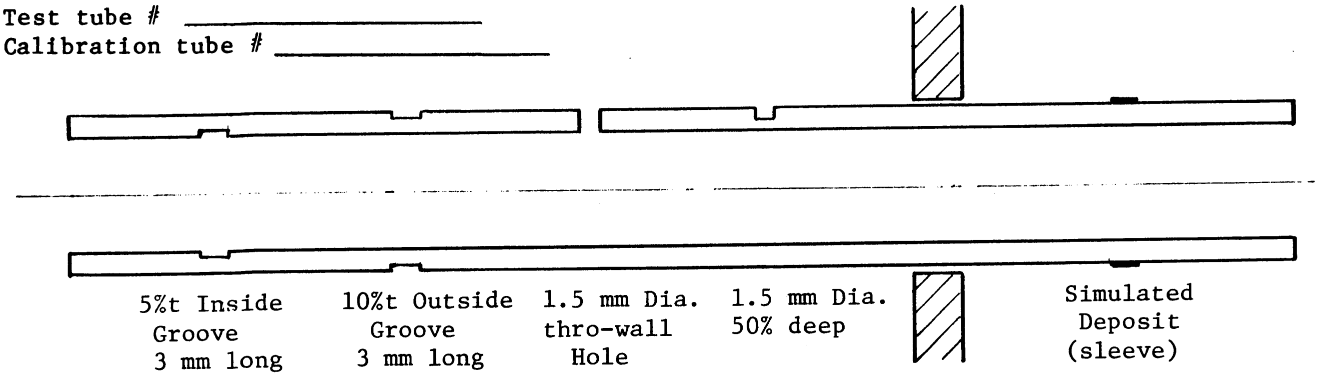
To inspect a heat exchanger tube, identify the signal source and, if a defect, estimate the extent of wall penetration.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ________________
Differential probe: ______________
Surface probe: ANDEC PAR500K.08 or equivalent.
Resistivity samples: BOEING CALIBRATION SAMPLES or equivalent range of samples.
Measuring dial caliper.

TEST AND CALIBRATION SAMPLES

Test tube # ____________________
Calibration tube # ___________________



PROCEDURE

Using surface probe and resistivity standards, estimate resistivity of calibration sample and test piece. Use this resistivity value to calculate the test frequency to make one wall thickness equal to 1.1 times standard depth of penetration, $t/\delta = 1.1$. Balance the instrument with absolute probe inside tube, set PHASE to give a negative X signal for the 5% ID defect, and set SENSITIVITY to yield a 2 V signal for the 1.5 mm thro-wall hole. Use a lower and higher frequency, if required, to differentiate between signals. For the differential probe, set phase so the ID defect traces a signal in the negative X direction first as the probe is retracted.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

RESULTS

Identify signal source; if it is a defect classify its depth as: less than 25% of wall, 25 to 50%, 50 to 75%, greater than 75%.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. 8.2(a)

PURPOSE

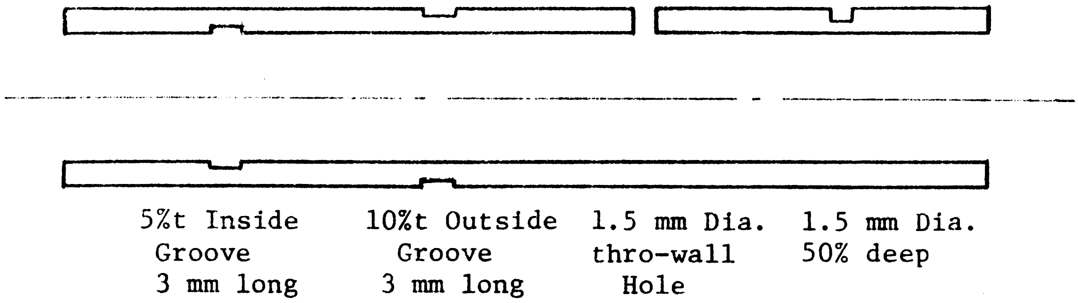
To determine a test frequency for inspecting a heat exchanger tube, using absolute and differential probes.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP400FA or equivalent.
Differential probe: ANDEC BP400FD or equivalent.

TEST AND CALIBRATION SAMPLE

Inconel 600 tube 13 mm O.D., 1.1 mm wall thickness (t), with calibration defects.



PROCEDURE

Experiment with test frequencies from 100 kHz to 300 kHz to get a 90° phase separation between the signals from ID and OD circumferential grooves to achieve this, balance instrument with absolute probe inside tube, set SENSITIVITY to yield a 2 V signal from the 1.5 mm hole. Set PHASE to give a negative X signal for the ID defect. For the differential probe, set PHASE such that the signal for the ID defect goes first in the negative X direction when probe is retracted.

RECORD

Sketch on the reverse side of page the X-Y signal images as seen on the storage monitor.

RESULTS

Calculate the t/δ ratio to give a 90° phase separation between the ID and OD defect signals. Use $\rho = 100\ \mu\Omega\text{-cm}$.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT
No. 8.2(b)

PURPOSE

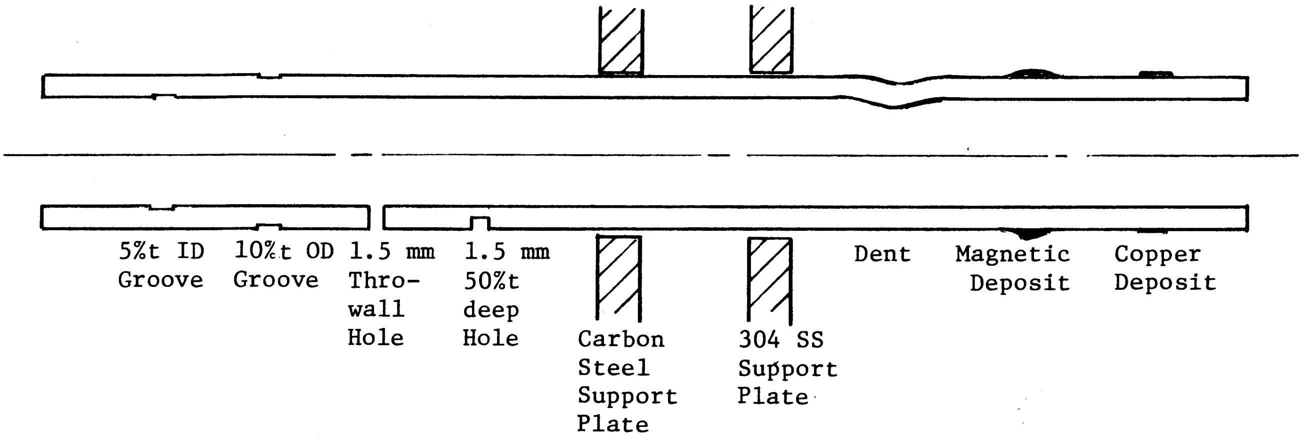
To study the behaviour of signals, at various frequencies, from standard calibration defects (I.D. groove, O.D. groove, and thro-wall hole) and other signal sources in an Inconel heat exchanger tube.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP400FA or equivalent.
Differential probe: ANDEC BP400FD or equivalent.

TEST AND CALIBRATION SAMPLE

Inconel 600 tube 13 mm O.D., 1.1 mm wall thickness (t), with calibration defects.



PROCEDURE

Calculate test frequency to make one standard depth of penetration (δ) equal to one wall thickness; use $\rho = 100\ \mu\Omega$-cm. Balance instrument with absolute probe inside tube, set PHASE to give a negative X signal for the ID defect, and set SENSITIVITY to suit. Scan the tube. For the differential probe, set PHASE such that the ID defect signal goes first in the negative X direction as the probe is retracted. Retest at half, and twice test frequency, observing change in signal appearance.

RECORD

Sketch on the reverse side of page, the X-Y signal images as seen on the storage monitor for each probe.

RESULTS

Observe the signal amplitude and phase for the various defects and other signal sources. Observe how they change with test frequency.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L8.3

PURPOSE

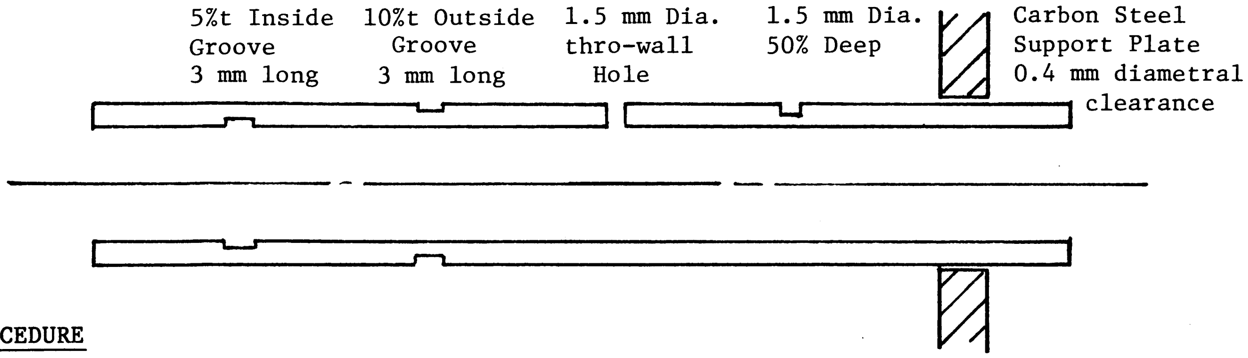
To inspect a heat exchanger tube, identify the signal source and, if a defect, the extent of wall penetration. A defective tube sample from the CRNL collection is used in this exercise. This tube has external attrition at a support plate.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP875BA or equivalent.
Differential probe: BP875BD or equivalent.
Surface probe: ANDEC PAR500K.08 or equivalent.
Resistivity samples: BOEING CALIBRATION SAMPLES or equivalent range of samples.
Measuring dial calipers.

TEST AND CALIBRATION SAMPLES

Test sample: Section of tubing with service-related defects (CRNL No. H515T).
Calibration sample: Length of similar tubing with calibration defects (CRNL No. H515C).



PROCEDURE

Using surface probe and resistivity samples estimate resistivity of calibration sample and test piece. Use this resistivity value to calculate the test frequency to make one wall thickness equal to 1.1 times standard depth of penetration, $t/\delta = 1.1$. Balance the instrument with absolute probe inside tube, set PHASE to give a negative X signal for the ID defect, and set SENSITIVITY to yield a 2 volt signal from the 1.5 mm thro-wall hole. Use a lower and higher frequency, if required, to differentiate between signals.
For the differential probe, set the PHASE so the ID defect traces a signal in the negative X direction first as the probe is retracted.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

RESULTS

Identify signal source, if it is a defect estimate its depth as: less than 25% of wall, 25 to 50%, 50 to 75%, greater than 75%.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L8.4

PURPOSE

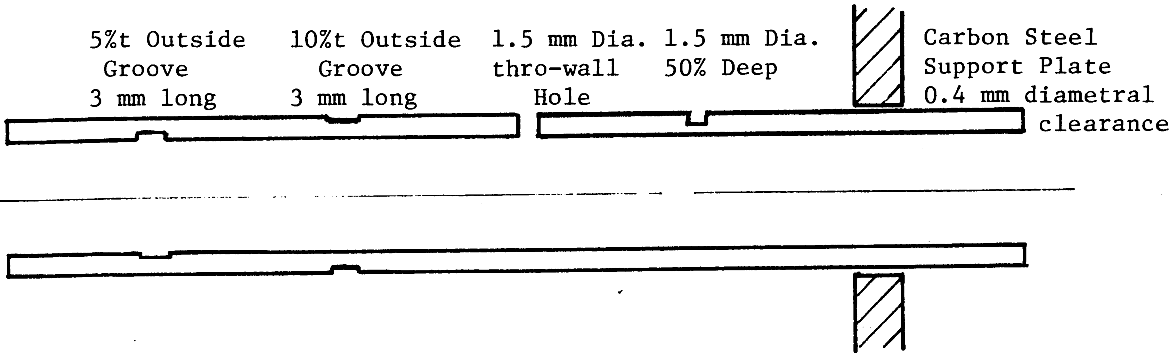
To inspect a heat exchanger tube, identify the signal source and if a defect, the extent of wall penetration. A defective tube sample from the CRNL collection is used in this exercise. This tube has cracks induced by stress corrosion.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP600EA or equivalent.
Differential probe: BP600ED or equivalent.
Surface probe: ANDEC PAR500K.08 or equivalent.
Resistivity samples: BOEING CALIBRATION SAMPLES or equivalent range of samples.
Measuring dial calipers.

TEST AND CALIBRATION SAMPLES

Test sample: Section of tubing with service-related defects (CRNL No. K439T).
Calibration sample: Length of similar tubing with calibration defects (CRNL No. K243C).



PROCEDURE

Using surface probe and resistivity samples estimate resistivity of calibration sample and test piece. Use this resistivity value to calculate the test frequency to make one wall thickness equal to 1.1 times standard depth of penetration, $t/\delta = 1.1$. Balance the instrument with absolute probe inside tube, set PHASE to give a negative X signal for the ID defect, and set SENSITIVITY to yield a 2 volt signal from the 1.5 mm thro-wall hole. Use a lower and higher frequency, if required, to differentiate between signals.
For the differential probe, set the PHASE so the ID defect traces a signal in the negative X direction first as the probe is retracted.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

RESULTS

Identify signal source, if it is a defect estimate its depth as: less than 25% of wall, 25 to 50%, 50 to 75%, greater than 75%.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L8.5

PURPOSE

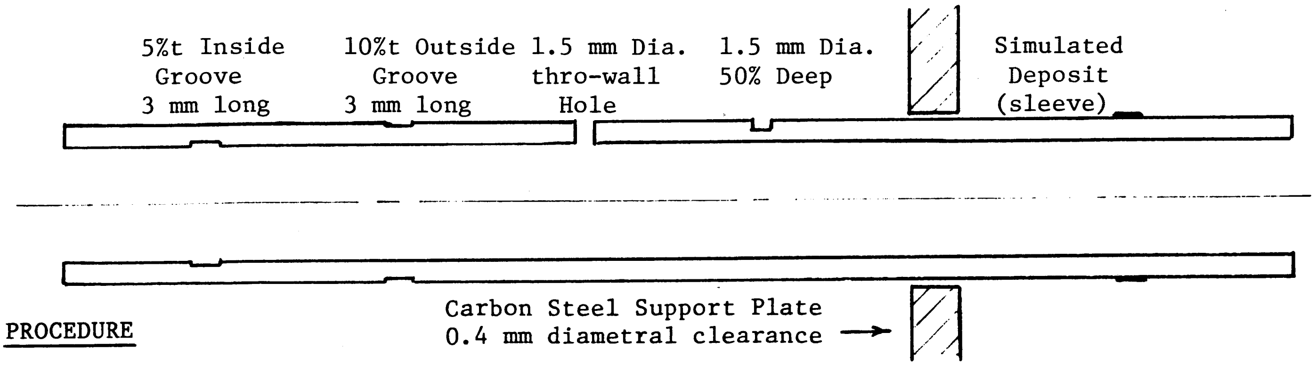
To inspect a heat exchanger tube, identify the signal source and if a defect, the extent of wall penetration. A defective tube sample from the CRNL collection is used in this exercise. This tube has external attrition caused by corrosion.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP600EA or equivalent.
Differential probe: ANDEC BP600ED or equivalent.
Surface probe: ANDEC PAR500K.08 or equivalent.
Resistivity samples: BOEING CALIBRATION SAMPLES or equivalent range of samples.
Measuring dial calipers.

TEST AND CALIBRATION SAMPLES

Test sample: Section of tubing with service-related defects (CRNL No. K442T).
Calibration sample: Length of similar tubing with calibration defects (CRNL No. K442C).



PROCEDURE

Using surface probe and resistivity samples estimate resistivity of calibration sample and test piece. Use this resistivity value to calculate the test frequency to make one wall thickness equal to 1.1 times standard depth of penetration, $t/\delta = 1.1$. Balance the instrument with absolute probe inside tube, set PHASE to give a negative X signal for the ID defect, and set SENSITIVITY to yield a 2 volt signal from the 1.5 mm thro-wall hole. Use a lower and higher frequency, if required, to differentiate between signals.
For the differential probe, set the PHASE so the ID defect traces a signal in the negative X direction first as the probe is retracted.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

RESULTS

Identify signal source, if it is a defect estimate its depth as: less than 25% of wall, 25 to 50%, 50 to 75%, greater than 75%.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L8.6

PURPOSE

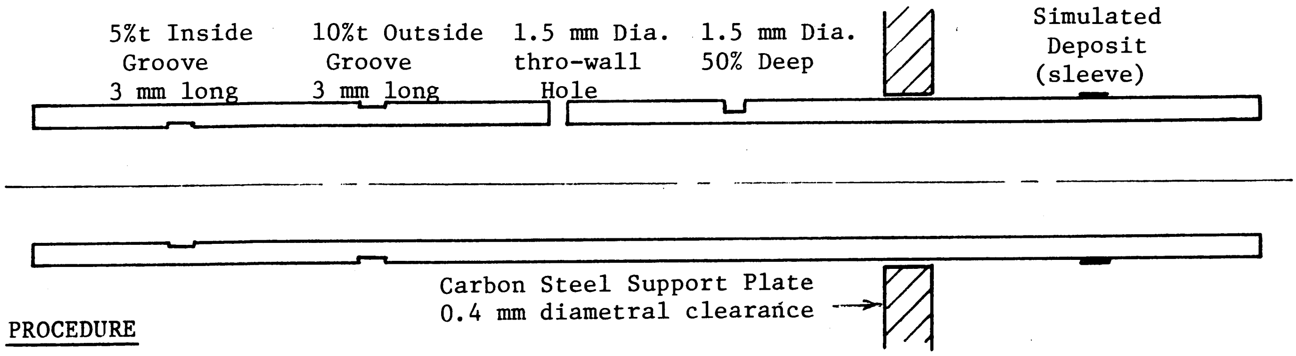
To inspect a heat exchanger tube, identify the signal source and if a defect, the extent of wall penetration. A defective tube sample from the CRNL collection is used in this exercise. This tube has inside pitting.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: ANDEC BP525AA or equivalent.
Differential probe: ANDEC BP525AD or equivalent.
Surface probe: ANDEC PAR500K.08 or equivalent.
Resistivity samples: BOEING CALIBRATION SAMPLES or equivalent range of samples.
Measuring dial calipers.

TEST AND CALIBRATION SAMPLES

Test sample: Section of tubing with service-related defects (CRNL No. H307T).
Calibration sample: Length of similar tubing with calibration defects (CRNL No. H307C).



PROCEDURE

Using surface probe and resistivity samples estimate resistivity of calibration sample and test piece. Use this resistivity value to calculate the test frequency to make one wall thickness equal to 1.1 times standard depth of penetration, $t/\delta = 1.1$. Balance the instrument with absolute probe inside tube, set PHASE to give a negative X signal for the ID defect, and set SENSITIVITY to yield a 2 volt signal from the 1.5 mm thro-wall hole. Use a lower and higher frequency, if required, to differentiate between signals.
For the differential probe, set the PHASE so the ID defect traces a signal in the negative X direction first as the probe is retracted.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

RESULTS

Identify signal source, if it is a defect estimate its depth as: less than 25% of wall, 25 to 50%, 50 to 75%, greater than 75%.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT

No. 8.7(a)

PURPOSE

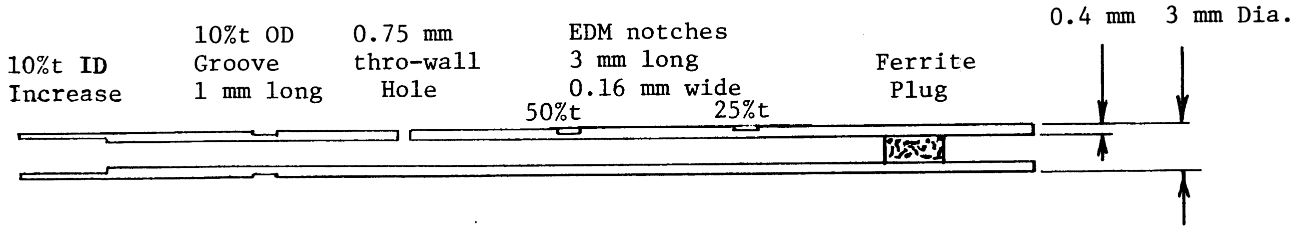
To study the behaviour of signals from calibration defects in small-bore 304 S.S. tubing using a normal test frequency, f_{90} and to observe the effects of using a lower test frequency.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe: encircling coil, 3.2 mm inside diameter
Differential probe: encircling coil, 3.2 mm inside diameter
Large horseshoe magnet.

TEST AND CALIBRATION SAMPLE

Calibration sample: stainless steel tube, 3 mm diameter, containing defects (CRNL No. 8.7) as shown below.



PROCEDURE

Calculate test frequency to make one standard depth of penetration equal to one wall thickness, use $\rho = 72$ $\mu\Omega$-cm. Balance instrument with tube in encircling probe, set PHASE to give a negative X signal for the OD defect, and set SENSITIVITY to yield a 2 volt signal for the thro-wall hole.
For the differential probe, set PHASE so the OD defect traces first a signal in the negative X direction as the probe is retracted.
Retest at 1/5 original test frequency observing change in signal orientation.
Place the magnet over the probe and retest at this frequency.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

OBSERVATIONS

Observe the signal phase for the various defects and other signal sources. The phase angle difference between defect signals and the ferrite plug is a result of phase lag across the tube wall. Observe how the signals change with test frequency. At the lower test frequency the phase separation of the signal from the ferromagnetic plug and the defects is about 90°. Refer to Section 8.3.1 of Eddy Current Manual, Volume 1 for an explanation.

Note the ferromagnetic signals are reduced in the presence of a magnet.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXERCISE
No. L8.7(b)

PURPOSE

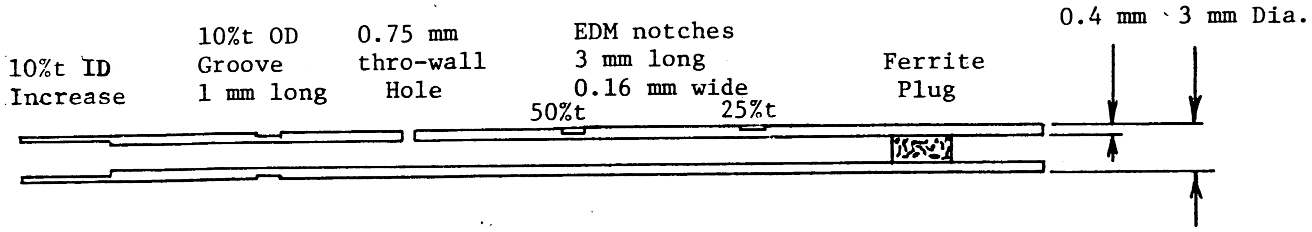
To inspect a small diameter 304 SS tube, identify the signal source (electrical resistivity, magnetic permeability or defect); if a defect, estimate the extent of wall penetration. A defective tube sample from the CRNL collection is used in this test. This tube has manufacturing flaws.

EQUIPMENT

Eddy current instrument: Automation Industries EM330 or equivalent.
Absolute probe: encircling coil 3.2 mm inside diameter.
Differential probe: encircling coil 3.2 mm inside diameter.

TEST AND CALIBRATION SAMPLE

Test sample: Stainless steel tube, 3 mm diameter, containing manufacturing defects (CRNL NO. 8.7B)
Calibration sample: Length of similar tubing with calibration defects below (No. 8.7).



PROCEDURE

Determine suitable test frequencies. Balance the instrument with tube in absolute probe, set PHASE with probe wobble horizontal and the signal from the OD defect in the negative X direction, and select suitable SENSITIVITY. Compare signals from calibration defects. Use differential probe if necessary to assist evaluation.

RECORD

Sketch on the reverse side of page the signal images seen on the storage monitor.

RESULTS

Identify signal source(s): (resistivity, permeability, dent or defect). If a defect, specify ID or OD and estimate the depth of the deepest defect, and note its location.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT
No. L9.1

PURPOSE

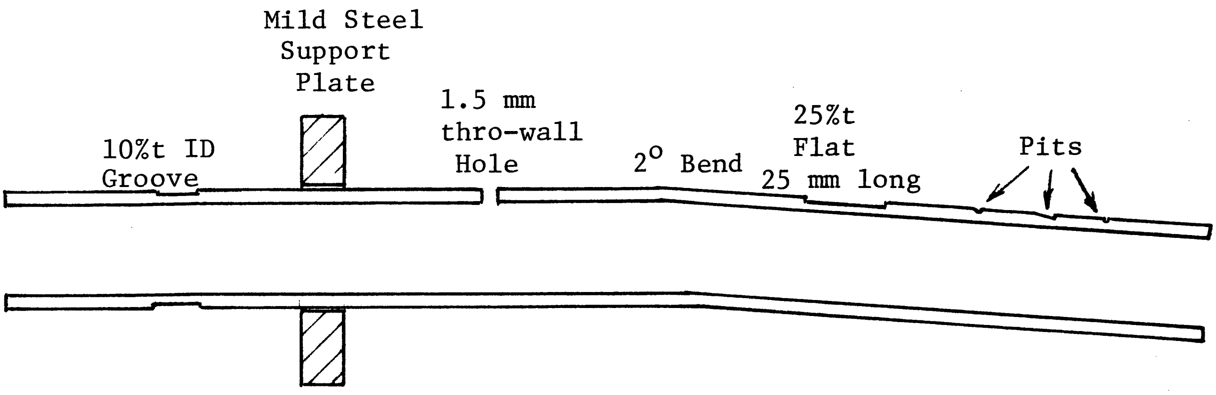
To inspect ferromagnetic Monel 400 tubes without and with magnetic saturation.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Absolute probe (without saturation): ANDEC BP375DA or equivalent.
Absolute saturation probe: ANDEC special series.
Two channel strip chart recorder: HP 7402A or equivalent.

TEST AND CALIBRATION SAMPLE

Length of Monel 400 tubing 12.7 mm O.D., 1.2 mm wall, with machined defects and a slight bend, as shown below (CRNL No. A2).



PROCEDURE

At test frequency f_{90} i.e., $\frac{t}{\delta} = 1.1$, balance the instrument with probe (without saturation) inside tube; use $\rho = 48\ \mu\Omega$-cm for calculation. Set PHASE to give a predominantly horizontal signal for probe wobble. Set SENSITIVITY to yield a 2 volt signal for the thro-wall hole. Scan tube length. Repeat with saturation probe.

RECORD

Sketch on the reverse side of page the X-Y signal images as seen on the storage monitor. Also record the X and Y components of the signals on strip chart recorder.

OBSERVATIONS

The signal-to-noise with the conventional probe (without saturation) is extremely poor whereas permeability variations due to cold work and internal stresses at the slight bend in the tube are completely suppressed by the saturation probe. When using the saturation probe the X-Y impedance signals from defects are the same as those from non-ferromagnetic tubes. A magnetically saturated tube appears non-ferromagnetic for eddy current purposes because incremental permeability is 1.0.

CALCULATIONS AND/OR OBSERVATIONS

EDDY CURRENT LABORATORY EXPERIMENT
No. L9.2

PURPOSE

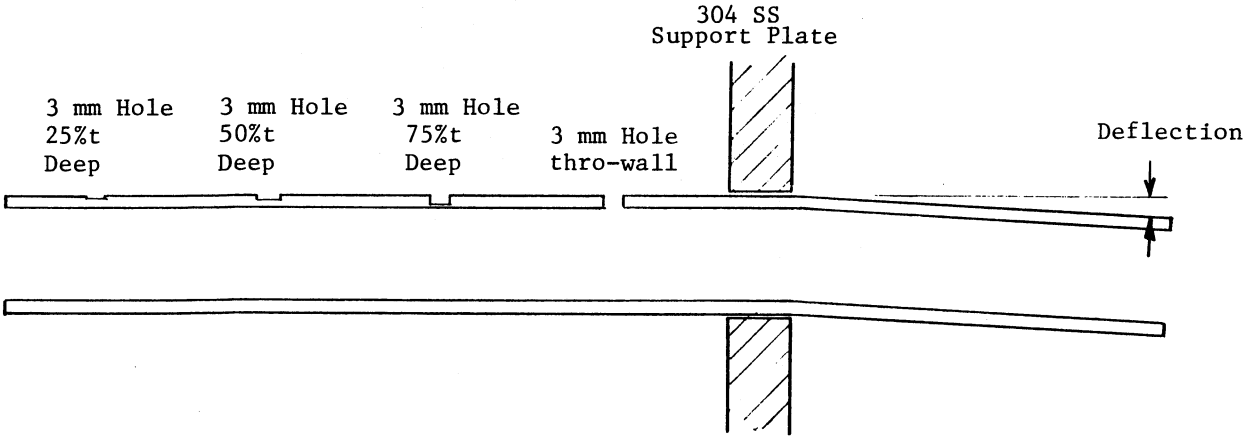
To inspect a ferromagnetic 3Re60 tube under elastic strain with partial saturation and with complete saturation.

EQUIPMENT

Eddy current instrument: Automation Industries EM3300 or equivalent.
Differential probe: (partial saturation) ANDEC special series.
Differential probe: (complete saturation) ANDEC special series.

TEST AND CALIBRATION SAMPLE

Length of 3 RE60 tubing 15.9 mm O.D., 1.1 mm wall, with machined defects, a bend, and a stainless steel support plate as shown below (CRNL No. S522 and S523).



PROCEDURE

At the test frequency f_{90}, $\frac{t}{\delta} = 1.1$, balance the instrument with the partial saturation probe inside the tube; use $\rho = 87\ \mu\Omega$-cm. Set PHASE so the OD defect traces a signal in the positive Y (vertically upward) direction first, as the probe is retracted. Scan tube length and repeat for various elastic deflections. Repeat with complete saturation probe.

OBSERVATIONS

Observe, when using the partial saturation probe, the calibration defects yield signals that change in phase with increasing depth, leading to the conclusion that one may have a viable test technique. However, elastic deflection of the tube at a support plate gives change of permeability signals nearly identical to serious defects (approximately 75% deep). When the probe capable of completely saturating the tube was used, the support plate signal looked normal, i.e., no defect.

CALCULATIONS AND/OR OBSERVATIONS

SECTION 3 - MULTIPLE CHOICE QUESTIONS

This section contains 100 eddy current questions typical of Canadian General Standards Board (CGSB) certification questions. They cover basic eddy current theory, equipment limitations, inspection requirements, and data analysis. A few basic ASNDT certification questions are also included. These questions are intended to check students' comprehension of the eddy current course material and to prepare them for CGSB exams. Commonly used formulae are included for reference at the beginning of this section.

The questions are divided into three levels of certification; Level I and II having four multiple choice answers and Level III, with five possible answers. They are further divided and labelled according to the Chapters in the "Eddy Current Manual, Volume 1", as denoted by the first digit of the question number.

The answers are available in the "Eddy Current Manual, Volume 2 Supplement, Course Instructors Handbook".

NOTE: If both answers _b_ and _c_ are correct and answer _e_ is "both _b_ and _c_ above", then answer e is the only CORRECT answer.

FORMULAE COMMONLY USED IN ET

$V = IZ$

$V = IR$

$\delta = 50\sqrt{\rho/f\mu_r}$, mm

$\beta = x/\delta$, radians

$X_L = \omega L$

$\omega = 2\pi f$

$X_c = 1/\omega C$

$\Theta = \text{Arctan}\ (X_L/R)$

$Z = \sqrt{R^2 + (\omega L)^2}$

$f_r = 1/2\pi\sqrt{LC}$

$Q = X_L/R$

$L = 4\pi \times 10^{-10}\ \mu_r N^2 A/\ell$

t/δ = constant

$P_c = \bar{r}^2 \omega \mu_r \sigma$ = constant

$P_c = 7.9 \times 10^{-4}\ \bar{r}^2 f/\rho$ = constant

$f_{90} = 3\ \rho/t^2$, kHz

$f_g = 5.07\ \rho/\mu_r D_i t$

$f_g = 5.07\ \rho/\mu_r D_o{}^2$

f/f_g = constant

$\eta = (\bar{D}/D_i)^2$

$\eta = (D_o/\bar{D})^2$

$\%$ IACS = $172/\rho$

$\phi = BA$

$\mu = B/H$

$\mu_o = 4\pi \times 10^{-7}$ webers/ampere-metre

$\mu_r = \mu/\mu_o$

1.1 (I) Eddy current method is normally used to detect subsurface defects in conductors to a maximum depth of:

a. 5 mm
b. 50 mm
c. 1 metre
d. any depth is possible by lowering test frequency

1.2 (I) Eddy current NDT method can be used to detect:

a. defects in thin material
b. surface defects in thick material
c. variations in electrical resistivity
d. all of the above

1.3 (II) A major problem associated with the eddy current test method is the:

a. inability of eddy current testing to accurately measure conductivity
b. need to test at slow speeds because of low test frequencies
c. large number of known or unknown variables which may influence the output indication
d. inability of eddy current testing to detect small discontinuities

1.4 (III) Circle the incorrect statement

a. eddy current testing is based on the process of inducing currents into a conductor and observing the interaction between the currents and the material
b. the eddy currents are monitored by observing the effect of their associated electromagnetic field on the electrical impedance of the test coil
c. in eddy current testing direct electrical contact with the sample is not required
d. eddy currents can be induced only in the first layer of a multilayer sample even at low test frequencies
e. eddy currents can be induced in ferromagnetic steels

1.5 (III) Eddy current testing can be used to detect:

a. laminations in plates
b. lack of weld penetration in thick stainless steel pipes
c. internal defects in small diameter tubing
d. lack of bond in plating
e. all of the above

2.6 (I) Which of the following best describes the meaning of IACS?

a. international standard for magnetic permeability
b. international standard for electrical conductivity
c. international standard for capacitance
d. international standard for alternating current

2.7 (I) Eddy currents are circulating currents induced in a conducting material by:

a. electrical contact
b. a standing wave front
c. a direct current field
d. a varying magnetic field

2.8 (I) A decrease in conductivity is equivalent to a/an:

a. increase in permeability
b. increase in resistivity
c. decrease in permeabiliity
d. decrease in resistivity

2.9 (I) In the eddy current test method the current is induced in a conductor from a:

a. stationary magnetic field from a strong magnet
b. coil carrying direct current (DC)
c. coil carrying alternating current (AC)
d. current flowing directly through the sample by electrical contact

2.10 (I) Which of the following test frequencies would produce eddy currents with the largest depth of penetration?

a. 100 Hz
b. 10 kHz
c. 1 MHz
d. 10 MHz

2.11 (I) A term used to define a material having a relative magnetic permeability larger than 1 is:

a. ferromagnetic
b. conductor
c. semiconductor
d. insulator

2.12 (I) Increasing test coil current will:

a. increase depth of penetration
b. decrease depth of penetration
c. not change depth of penetration
d. increase lift-off

2.13 (II) Which of the following materials would have the highest resistivity value?

a. aluminum with a 42% IACS rating
b. magnesium with a 37% IACS rating
c. cast steel with a 10.5% IACS rating
d. zirconium with a 3.4% IACS rating

2.14 (II) Penetration of eddy currents in a conductive material decreases when:

a. test frequency or conductivity of the specimen is decreased
b. test frequency is decreased or conductivity of the specimen is increased
c. test frequency, conductivity of the specimen or permeability of the specimen are increased
d. permeability of the specimen is decreased

2.15 (II) When a ferromagnetic metallic material is placed inside a test coil at low test frequencies, the flux density in the material is:

a. less than the flux density generated by the test coil because of heat losses
b. less than the flux density generated by the test coil because of resistivity
c. the same as the flux density generated by the test coil in air
d. greater than the flux density generated by the test coil in air

2.16 (II) The magnetic field generated by eddy currents induced in a nonferromagnetic test specimen:

a. opposes the magnetic field that induced the eddy currents
b. reinforces the magnetic field that induced the eddy currents
c. cancels the magnetic field that induced the eddy currents
d. has no effect on the magnetic field that induced the eddy currents

2.17 (II) Which of the following statements is <u>incorrect</u>?

a. a constant amplitude magnetic field exists around a coil carrying a constant current (DC)
b. a periodically varying magnetic field exists around a coil carrying a periodically varying current
c. when a coil carrying a constant current is adjacent to a conductor, constant currents (DC) are induced
d. when a coil carrying a periodically varying current is brought near a conductor, periodically varying currents are induced

2.18 (III) At a fixed test frequency, in which of the following materials will the eddy current penetration be greatest?

a. aluminum (35% IACS)
b. brass (15% IACS)
c. bronze (12% IACS)
d. copper (100% IACS)
e. iron (10% IACS)

2.19 (III) The signal from a:

a. defect depends only on the induced current density
b. defect depends on its size and is independent of test frequency
c. surface defect is the same as that from a subsurface defect
d. subsurface defect depends on the eddy current density and phase lag
e. subsurface defect increases in amplitude with depth because of increased current density and phase lag

2.20 (III) The decrease in eddy current density with depth into the sample is affected by:

a. test frequency
b. surface probe coil diameter or internal probe coil width
c. sample's resistivity and magnetic permeability
d. presence of large defects
e. all of the above

3.21 (I) The total opposition to flow of alternating current in an eddy current test coil is called:

a. resistance
b. inductive reactance
c. impedance
d. capacitive reactance

3.22 (I) The induced voltage produced by magnetic flux linking the turns of a test coil depends upon the following:

a. amount of magnetic flux
b. time rate of change of magnetic flux
c. number of turns
d. all of the above

3.23 (I) The symbol commonly used to signify inductance is:

a. Z
b. X_L
c. L
d. I

3.24 (I) The impedance of a coil or probe is measured in units of:

a. mhos
b. ohms
c. henrys
d. amperes

3.25 (I) The inductive reactance of a coil is measured in units:

a. mhos
b. ohms
c. henrys
d. gauss

3.26 (I) The impedance of an eddy current test coil will:

a. increase with increasing test frequency
b. decrease with increasing test frequency
c. not change with increasing test frequency
d. be less than the inductive reactance at high test frequency

3.27 (II) The formula used to calculate magnitude of the impedance of an eddy current test coil is:

a. $Z = 2\pi fL$
b. $Z = X_L + R$
c. $Z = \sqrt{X_L + R}$
d. $Z = \sqrt{X_L^2 + R^2}$

3.28 (II) Change in a sample's electrical resistivity results in a change in test coils:

a. resistance only
b. inductance only
c. impedance
d. none of the above

3.29 (II) If a probe is brought close to a ferrite ($\mu_r >> 1$) sample the probe:

a. impedance will increase
b. inductance will decrease
c. resistance will increase
d. none of the above

3.30 (II) The impedance of a test coil adjacent to a thin sample can be described as a/an:

a. resistor
b. inductor
c. resistor in parallel with an inductor
d. capacitor in series with an inductor

3.31 (II) Circle the correct statement.

- a. an increase in sample resistivity will move the operating point DOWN the normalized impedance curve
- b. an increase in probe diameter will move the operating point DOWN the normalized impedance curve
- c. an increase in test frequency will move the operating point UP the normalized impedance curve
- d. an increase in sample thickness will move the operating point UP the normalized impedance curve

3.32 (III) Which of the following does not affect the operating point on the normalized impedance diagram

- a. probe diameter
- b. number of turns in a coil
- c. test frequency
- d. sample resistivity
- e. sample permeability

3.33 (III) At all normal test frequencies, the presence of a subsurface defect changes the probe's:

- a. resistance
- b. inductance
- c. impedance
- d. coupling
- e. capacitance

3.34 (III) Circle the correct statement

- a. a defect will primarily change the probe's resistance
- b. a change in sample's geometry will primarily change the probe's inductance
- c. a change in resistivity will primarily change the probe's resistance
- d. a change in permeability will primarily change the probe's inductance at low test frequencies
- e. lift-off primarily changes the probe's inductance at low test frequencies

4.35 (I) Conductivity instruments can be used to sort materials with different:

- a. electrical conductivity
- b. electrical resistivity
- c. magnetic permeability
- d. all of the above

4.36 (I) Test frequencies higher than 1 MHz are normally used to:

- a. detect surface cracks
- b. measure subsurface defects in copper
- c. measure wall thickness of copper tubing
- d. none of the above

5&6.49 (I) Which of the following should not be tested by the eddy current testing method?

a. a 20 mm thick plate to be tested for small interior discontinuities
b. tubing to be tested for surface cracks
c. rod to be tested for laps and seams
d. tubing to be tested for variations in outside diameter

5&6.50 (I) The inductance of a coil increases with:

a. number of turns
b. diameter of coil
c. permeability of the core
d. all of the above

5&6.51 (I) Typical probe impedance change in the presence of a defect is:

a. 1%
b. 10%
c. 25%
d. 50%

5&6.52 (II) When estimating the electrical resistivity of a thick aluminum alloy ($\rho = 5\ \mu\Omega$ .cm) with a 10 mm diameter probe the test frequency should be:

a. the lowest available on the eddy current instrument (<1 kHz)
b. low to intermediate (2-50 kHz)
c. as high as possible (>500 kHz)
d. any test frequency

5&6.53 (II) During measurement of conductivity of a specimen the effect of (error from) variations in test part thickness can be reduced by:

a. increasing test frequency
b. decreasing test frequency
c. decreasing fill-factor
d. there is no practical method for reducing this effect

5&6.54 (II) Which factor would cause the greatest change in impedance of a coil above a conducting plate (with all other factors remaining constant)?

a. a lift-off variation equal to 10% of the coil mean radius
b. a 10% change in conductivity
c. a 10% change in plate thickness
d. a 20% change in plate density

4.43 (III) Which of the following is NOT a method that may generally be used to improve signal-to-noise ratio?

a. change to a test frequency that will decrease the noise
b. increase amplification of the test instrument
c. increase fill factor
d. add filter circuits to the instrument
e. magnetically saturate the material during inspection

4.44 (III) Two test coils are often used in a bridge circuit to:

a. increae depth of penetration
b. make possible bridge balance
c. increase the conductivity of the circuit
d. decrease the system sensitivity
e. double the bridge inductance

4.45 (III) Crack detectors normally used for defect detection on high electrical resistivity materials, such as stainless steel, could be used to:

a. detect subsurface cracks in aluminum
b. detect surface cracks in brass
c. measure wall thickness in airplane wings
d. sort materials with low electrical resistivity
e. none of the above

4.46 (III) Crack detectors cannot be used to detect deep subsurface defects, primarily because:

a. they have no lift-off compensation
b. they operate at a single high test frequency, thereby limiting eddy current penetration
c. they have only a meter output
d. they are very sensitive to material's resistivity variations
e. the meter output has insufficient range

4.47 (III) When a general purpose bridge type eddy current instrument is used with an input impedance of 75 ohms,

a. a probe impedance of 75 ohms should not be used because of possible probe-instrument resonance
b. a probe impedance at least 500 ohms should be used to ensure a high probe excitation voltage
c. a probe impedance less than 5 ohms should be used to ensure a high probe excitation current
d. a probe impedance between 15 and 200 ohms will work satisfactorily except at probe-cable resonance
e. none of the above

5&6.48 (I) Lift-off is utilized in:

a. measuring permeability changes
b. measuring conductivity changes
c. measuring the thickness of non-conductive coatings
d. determining proper test frequency

5&6.49 (I) Which of the following should not be tested by the eddy current testing method?

a. a 20 mm thick plate to be tested for small interior discontinuities
b. tubing to be tested for surface cracks
c. rod to be tested for laps and seams
d. tubing to be tested for variations in outside diameter

5&6.50 (I) The inductance of a coil increases with:

a. number of turns
b. diameter of coil
c. permeability of the core
d. all of the above

5&6.51 (I) Typical probe impedance change in the presence of a defect is:

a. 1%
b. 10%
c. 25%
d. 50%

5&6.52 (II) When estimating the electrical resistivity of a thick aluminum alloy ($\rho = 5\ \mu\Omega$ .cm) with a 10 mm diameter probe the test frequency should be:

a. the lowest available on the eddy current instrument (<1 kHz)
b. low to intermediate (2-50 kHz)
c. as high as possible (>500 kHz)
d. any test frequency

5&6.53 (II) During measurement of conductivity of a specimen the effect of (error from) variations in test part thickness can be reduced by:

a. increasing test frequency
b. decreasing test frequency
c. decreasing fill-factor
d. there is no practical method for reducing this effect

5&6.54 (II) Which factor would cause the greatest change in impedance of a coil above a conducting plate (with all other factors remaining constant)?

a. a lift-off variation equal to 10% of the coil mean radius
b. a 10% change in conductivity
c. a 10% change in plate thickness
d. a 20% change in plate density

5&6.55 (II) To make a thickness measurement of a plate ($\rho = 2.5$ microhm.cm) with a nominal thickness of 0.25 mm. The best frequency for a surface coil with a 1 mm mean radius is:

a. 100 Hz
b. 2 kHz
c. 50 kHz
d. 5 MHz

5&6.56 (II) Many general purpose eddy current instruments cannot operate at the probe-cable resonance frequency. This problem occurs:

a. at high test frequency
b. with long cable lengths
c. with high capacitance cables
d. all of the above

5&6.57 (II) The characteristic parameter, $\bar{r}^2\omega\mu\sigma$, can be used to calculate or establish the:

a. separate effect of $\bar{r}$, ω , μ and σ (as a single parameter) on the operating point on the impedance diagram
b. test frequency to operate at the knee location of the impedance diagram (for a given coil diameter)
c. conditions of similarity
d. all of the above

5&6.58 (II) When testing a thick material for surface or near surface defects the test frequency should be chosen to:

a. operate close to the knee location on the impedance diagram
b. allow maximum penetration
c. allow discrimination between defects and probe wobble signals
d. maximize probe-to-sample coupling

5&6.59 (II) A zirconium alloy ($\rho = 72$ $\mu\Omega$.cm) plate nominally 1 mm thickness is being inspected for defects (volumetric inspection) using a surface probe. Inspection frequency should be:

a. 1 kHz
b. 10 kHz
c. 100 kHz
d. 1 MHz

5&6.60 (II) Eddy current surface probes 15 mm in diameter would normally be used to inspect for:

a. 1 mm diameter surface pits
b. changes in material conductivity
c. 2 mm long surface cracks
d. deep laminations

5&6.61 (III) Ferrite cores are normally used in small diameter probes (or low frequency probes) to:

a. obtain a higher inductance (than an air core probe) for a given coil size
b. obtain a higher inductance (than an air core probe) for the same number of turns
c. decrease the surface area in contact with the specimen
d. increase the coupling into the test piece (for the same coil-to-specimen spacing)
e. all of the above

5&6.62 (III) To ensure reliable flaw detection, the maximum velocity of a part past an inspection coil must be limited. This limitation is determined by:

a. the inspection coil length of bobbin probes or diameter of surface probes
b. the desired flaw size resolution
c. the eddy current instrument frequency response
d. the recording equipment frequency response
e. all of the above

5&6.63 (III) Which of the following parameters or material properties would normally give characteristically different signals?

a. lift-off and wall thickness
b. cold work and impurities in a non-ferromagnetic material
c. hardness and electrical resistivity in a non-ferromagnetic material
d. lift-off and non-conducting layer on a conductor surface
e. none of the above

5&6.64 (III) When measuring for wall thickness it is better to use:

a. very low frequencies
b. very large probes and high test frequencies
c. very small probes independent of test frequency
d. frequency such that one standard depth of penetration approximately equals wall thickness, $\delta \doteqdot t$
e. high or low frequency depending on probe size and determined by laboratory tests

5&6.65 (III) Thick wall specimens (>10 mm) cannot be inspected for defects throughout their thickness mainly becaue of the:

a. attenuation due to skin depth effect
b. decrease in eddy current density due to practical coil diameter
c. electrical resistivity
d. edge effect
e. operating point is always below the knee location on the impedance diagram

5&6.66 (III) If it is possible to inspect a plate 2.5 mm thick for defects throughout its thickness at f = 500 kHz, is it possible to inspect a plate 25 mm thick for similar defects throughout its thickness at:

a. 0.5 kHz
b. 5 kHz
c. 50 kHz
d. not inspectable at any test frequency
e. only possible with 25 mm diameter probe

5&6.67 (III) While testing a stainless steel casting an indication was obtained. As the test frequency was lowered from 300 kHz to 30 kHz the signal phase increased from 30° to 75° relative to the lift-off signal. The indication could be due to a/an:

a. surface crack
b. subsurface crack
c. decrease in electrical resistivity
d. increase in electrical resistivity
e. change in magnetic permeability

5&6.68 (III) While testing an aluminum casting an indication was obtained. The signal relative to the lift-off signal was approximately 30° at 10 kHz, 90° at 100 kHz and 145° at 300 kHz. The indication was due to a:

a. surface crack
b. surface ferromagnetic inclusion
c. subsurface ferromagnetic inclusion
d. subsurface defect
e. both b and d above

5&6.69 (III) When inspecting with surface type probes, the signal from a subsurface defect appears characteristically different than that from a surface defect. This is due to a/an:

a. increase in resistance due to the larger flow path below the surface
b. decrease in current density below the surface (skin depth attenuation)
c. increase in phase lag with depth
d. increase in coil inductance
e. increase in coil coupling

5&6.70 (III) A two layer aluminum structure has to be inspected for possible through wall cracks in the bottom layer. Each layer is 1 mm thick and the electrical resistivity is 4.0 microhm·centimetre. What test frequency should be used?

a. 100 to 500 kHz
b. 20 to 50 kHz
c. 2 to 10 kHz
d. a high frequency crack detector should be used
e. cannot be inspected because eddy currents cannot be induced on the second layer

5&6.71 (III) Shallow surface defects are difficult to detect because:

a. the signal is similar to probe wobble with surface probes (or with internal tube probes for internal surface defects)
b. the signal is similar to a change in electrical resistivity
c. the signal is similar to a change in magnetic permeability
d. the signal amplitude is too small to measure even for long defects and high instrument sensitivity
e. statement is not true, shallow surface defects can easily be detected if they are long

5&6.72 (III) A crack 0.5 mm deep and 10 mm long and 0.02 mm wide was detected in a brass plate using a 5 mm diameter surface probe. A machined calibration defect of the same length and depth was available, but was 0.2 mm wide. The signal:

a. from the calibration defect was approximately 10 times larger than the real crack signal
b. from the calibration defect was approximately 10 times less than the real crack signal
c. was approximately the same for both defects
d. from a machined defect cannot be used to predict the the depth of a real crack
e. amplitude from the real crack is always greater than the calibration defect because of the greater magnetic reluctance

7&8.73 (I) Which of the following would normally be considered the best fill-factor for testing straight tubing with an encircling or internal probe.

a. 0.80 (80%)
b. 1.75 (175%)
c. 0.50 (50%)
d. 0.25 (25%)

7&8.74 (I) When eddy current testing a rod with an encircling coil, which of the following conditions would be most difficult to detect?

a. a deep surface crack that has a depth of 30% of the rod diameter
b. a small inclusion in the center of the rod
c. a 5% change in diameter
d. a 10% change in conductivity

7&8.75 (I) During an eddy current test on tubing, the amplitude of the indication from a discontinuity depends on:

a. depth of the discontinuity
b. width of the discontinuity
c. length of the discontinuity
d. all of the above

7&8.76 (I) A length of tubing containing a notch running from end to end, having a uniform width and depth, when tested with an ideal, encircling, differential coil will produce:

a. erratic signals
b. a continuous, sustained signal
c. no signal
d. extraneous signals

7&8.77 (I) In eddy current testing with encircling probes, coupling efficiency is referred to as:

a. lift-off
b. edge effect
c. fill-factor
d. phase differentiation

7&8.78 (II) When a nonferromagnetic metallic rod is placed inside an eddy current test coil

a. the magnetic field generated by the coil is increased in intensity
b. the distribution of eddy currents is uniform through the rod's cross section
c. the eddy currents are maximum at the rod's surface and decrease to essentially zero at the rod's center
d. the eddy currents flow along the length of the rod

7&8.79 (II) When inspecting a tube with an internal probe for damage on the outside of the tube:

a. outside damage can easily be detected at all frequencies
b. there is an optimum frequency, usually at lower frequencies where depth of current penetration is higher
c. testing should be performed at frequencies of 100 kHz or greater
d. use only an absolute probe

7&8.80 (II) Heat exchanger tube inspection in the mill is normally performed using for calibration standards:

a. a series of notches and small holes
b. milled flats
c. all kinds of real defects
d. rejected tubes

7&8.81 (II) It is desired to inspect 12.5 mm diameter, 1 mm wall thickness, type 304 stainless steel tubing, for both circumferential and longitudinal cracks. Which type of coil would be best to use?

a. encircling differential coils
b. encircling absolute coils
c. a rotating surface probe coil
d. an internal coil

7&8.82 (II) Which of the following formulae is used to calculate the approximate test frequency for general tube inspection using internal or external probes?

a. $t/\delta = 1$
b. $f/f_g = 6.25$
c. $\bar{r}^2 \omega\mu\sigma = 10$
d. $f/f_g = 1$

where
t is wall thickenss
δ is one standard depth of penetration
$\bar{r}$ is average probe radius
ω is angular frequency
μ is magnetic permeability
σ is electrical conductivity
f_g is limit frequency
f is test frequency

7&8.83 (II) Forster's Characteristic or Limit Frequency, f_g can be used to:

a. calculate the fill-factor
b. calculate the phase lag across thick wall tubes
c. calculate the depth of penetration in tubes
d. none of the above

7&8.84 (II) During manual in-service heat exchanger inspection, the signal from baffle plates changed in amplitude. This could be due to a/an:

a. varying speed of insertion or extraction of probe (jerking motion)
b. presence of defects under some of the baffle plates
c. varying baffle plates thickness or hole size
d. all of the above

7&8.85 (II) During in-service inspection of heat exchanger tubes with an absolute probe, the signal changed gradually. This could be due to:

a. accumulation of magnetic deposit on front end of probe
b. increase in ambient temperature
c. gradual decrease in tube wall thickness
d. all of the above

7&8.86 (III) In developing a multifrequency test, the indications hardest to separate and eliminate are those with:

a. signals having the same phase as defect signals
b. 0° to 90° phase shifts relative to defect signals
c. no electrical relation with defect signals
d. 90° to 110° phase shift relative to defect signals
e. none of the above

7&8.87 (III) Dents in tubing produce signals during inspection with internal probes, at a frequency where $t \doteq \delta$, which:

a. often appear as a gain of metal
b. often appear as a loss of metal
c. have a phase angle 180° from internal pits
d. have a phase angle 180° from external pits
e. can be misinterpreted for internal ferromagnetic deposits

7&8.88 (III) Internal differential probes significantly decrease the effect of:

a. probe wobble
b. gradual magnetite build-up
c. gradual wall thickness variations
d. ambient temperature variations
e. all of the above

7&8.89 (III) Eddy current inspection of unsaturated ferromagnetic tubing is difficult and unreliable mainly because:

a. eddy current penetration is limited by high magnetic permeability
b. resistivity and permeability variations yield similar signals
c. resistivity and probe wobble variations yield similar signals
d. unimportant variations in magnetic permeability can obscure defect indications or give false indications
e. both a and b above

7&8.90 (III) When testing with an internal probe at a frequency such that wall thickness equals one standard depth of penetration it is possible to distinguish between the following signals:

a. probe wobble and shallow internal defects
b. probe wobble and shallow external defects
c. inside magnetic deposit and internal defects
d. corrosion damage and cracks, of the same depth
e. none of the above signals are distinguishable from each other

7&8.91 (III) When using multifrequency eddy current equipment for internal tube inspection, with a bobbin type internal probe, which of the following defects is it possible to detect?

a. shallow internal defects in the presence of probe wobble
b. shallow wear grooves under stainless steel baffle plates
c. shallow internal defects in the presence of 'pilger' noise (cyclic inside diameter variation)
d. circumferential cracks under baffle plates
e. none of the above

7&8.92 (III) In external tube testing (manufacturing inspection) an indication was obtained. At the test frequency, and at 5 times higher and 5 times lower frequency, the signal remained similar to probe wobble. The indication could be due to a/an:

a. internal defect
b. ferromagnetic inclusion
c. deep crack
d. external defect
e. dent or a shallow external defect

7&8.93 (III) The reason why an absolute probe rather than a differential probe is used by some inspectors is:

a. the signal from multiple defects is easier to analyze
b. both localized and long gradual defects can be located
c. wear under support plates can be detected easier and the depth can be estimated more accurately
d. all of the above
e. none of the above

9.94 (I) When testing ferromagnetic materials the major influencing factor is:

a. conductivity
b. permeability
c. resistance
d. none of the above

9.95 (II) The ratio of a material's flux density (B) to a test coil's magnetizing force (H) can be used to determine the material's

a. conductivity
b. resistivity
c. lift-off
d. permeability

9.96 (II) For age hardenable aluminum and titanium alloys, changes in hardness are usually indicated by changes in:

a. retentivity
b. permeability
c. conductivity
d. magnetostriction

9.97 (II) In testing tubes or plates a calibration standard is sometimes made with EDM (electron discharge machining) notches. They must be:

a. less than 0.1 mm wide
b. checked that the sides are parallel
c. checked for possible changes in magnetic permeability associated with the notches, if the material is stainless steel
d. checked for possible changes in electrical resistivity associated with the notches if the material is copper

9.98 (II) What is the meaning of magnetic permeability?

a. a measure of ability of material to support a magnetic field
b. a measure of gap between the probe and surface being tested
c. a measure of ability of material to conduct eddy currents
d. a measure of ability of a stationary permanent magnet to induce currents in a conductor

9.99 (III) Magnetic permeability must be taken into consideration in eddy current testing because it:

a. is one of the parameters affecting depth of penetration
b. changes magnetic reluctance thereby changing probe impedance
c. is variable in magnetic materials
d. changes the magnetic flux
e. all of the above

9.100 (III) You must inspect a 10 mm diameter lift cable, made of carbon steel braids 1 mm diameter, for broken braids. You should use:

a. leakage flux method, using permanent magnets to magnetize the cable
b. eddy current method at low frequencies (< 10 kHz)
c. eddy current method at high frequencies (< 100 kHz)
d. crack detectors for ferromagnetic materials
e. all of the above

ISSN 0067-0367

To identify individual documents in the series
we have assigned an AECL- number to each.

Please refer to the AECL- number when requesting additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price $7.00 per copy

ISSN 0067-0367

Pour identifier les rapports individuels faisant
partie de cette série nous avons assigné
un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si
vous demandez d'autres exemplaires de ce
rapport

au

Service de Distribution des Documents Office
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix $7.00 par exemplaire

3002-84