

ME5713: Nondestructive Testing

Esam M.A. Hussein, Ph.D., P.Eng.
Department of Mechanical Engineering
University of New Brunswick
Fredericton, N.B. E3B 5A3
E-mail: Hussein@UNB.CA
Tel: (506) 447-3105
Fax (506) 453-5025

December 5, 1996

These are course notes intended to guide you through the material covered in the course. They do not constitute by themselves a complete textbook. Please consult other sources for more details, specific data, graphs and illustrations.

December 5, 1996

C o n t e n t s

1	INTRODUCTION	1
1.1	Definition	1
1.2	Purpose	1
1.3	Methods	2
1.3.1	Passive Methods	2
1.3.2	Active Methods	2
1.4	Electromagnetic Radiation	2
1.5	Sound Waves (Vibrational Energy)	3
1.6	Uses of NDT	3
1.7	Motivations for NDT	4
1.8	Sensors	4
1.9	Basic Elements of NDT	4
1.10	NDT Techniques	5
1.10.1	Penetrant Testing	6
1.10.2	Ultrasonics	6
1.10.3	Acoustic Emission	6
1.10.4	Eddy Current	7
1.10.5	Magnetic Particle Testing	7
1.10.6	Microwaves	7
1.10.7	Radiography	7
1.10.8	Thermography	8
1.10.9	Miscellaneous Techniques	8
1.10.10	Techniques Covered in Course	8
1.11	Graphs	9
2	Ultrasonics	13
2.1	Introduction	13
2.2	Physics of Acoustic Waves	13
2.2.1	1-D Plane Waves	14

2.2.2	Plane Longitudinal Waves	15
2.2.3	Plane Transverse Waves	16
2.2.4	Bulk Waves	16
2.2.5	Surface Waves	16
2.2.6	Lamb Waves	17
2.3	Modification	17
2.3.1	Specific Acoustic Impedance	17
2.3.2	Reflection and Transmission Coefficients	18
2.3.3	Loss of Pulse Energy	21
2.4	Source/Sensor	21
2.4.1	Transducers	21
2.4.2	Acoustic Equivalence	22
2.4.3	Electric Equivalency	23
2.4.4	Couplants	23
2.4.5	Beam Spreading	24
2.4.6	Selecting Criteria	25
2.5	Indication	26
2.5.1	Normal Incidence	26
2.5.2	Angle Beam	27
2.5.3	Scanning Techniques	28
2.6	Interpretation and Applications	29
2.6.1	General	29
2.6.2	Examination of Welds	30
2.6.3	Pipe Inspection	30
2.6.4	Surface Wave Inspection	31
2.6.5	Lamb Wave Inspection	31
2.7	Work Problems	31
2.8	Graphs	33
3	Magnetic Flux Leakage	53
3.1	Introduction	53
3.1.1	Advantages	53
3.1.2	Disadvantages	54
3.2	Magnetism	54
3.2.1	Basic Parameters	54
3.2.2	Material Classification	55
3.3	Modification	57
3.4	Sources	58
3.4.1	Types	58
3.4.2	Field Lines	58

CONTENTS

v

3.4.3	Required Current	59
3.4.4	Circular Magnetization	59
3.4.5	Demagnetization	60
3.5	Detection	60
3.5.1	Magnetic Particles	60
3.5.2	Magnetic Rubber	60
3.5.3	Pickup Coils	61
3.5.4	Hall Elements	61
3.5.5	Magnetodiodes	61
3.5.6	Magnetic Recording Tapes	61
3.5.7	Förster Microprobes	62
3.6	Applications	62
3.6.1	Bars	62
3.6.2	Tubing	62
3.6.3	Plates	62
3.6.4	Weldments	62
3.7	Work Problems	62
3.8	Graphs	63
4	Eddy Current	73
4.1	Physics	73
4.2	General	75
4.2.1	Affecting Parameters	75
4.2.2	Advantages	75
4.2.3	Limitations	76
4.3	Coils	76
4.3.1	Absolute Coils	76
4.3.2	Differential coils	76
4.3.3	Combined Coils	77
4.3.4	Frequency	77
4.4	Special Effects	77
4.4.1	Edge Effect	77
4.4.2	Fill Factor	77
4.4.3	Lift Off	78
4.5	Analysis and Indication	78
4.5.1	Inductance	78
4.5.2	Impedance	78
4.5.3	Voltage and Current	79
4.5.4	Testing Methods	80
4.6	Remote-Field Testing	81

4.6.1 Schmidt Experiment	81
4.7 Work Problems	82
4.8 Graphs	83
5 Radiography	99
5.1 Introduction	99
5.2 Basic Physics and Modification	99
5.3 Sources	102
5.3.1 X-Rays	102
5.3.2 Gamma-Rays	103
5.4 Film Radiography	104
5.5 Indication	105
5.5.1 Unsharpness	105
5.5.2 Sensitivity	106
5.6 Calculation of X-ray Exposures	107
5.7 Safety and Protection	108
5.8 Work Problems	109
5.9 Graphs	109
6 Acoustic Emission	125
6.1 Introduction	125
6.1.1 Advantages	126
6.1.2 Disadvantages	126
6.1.3 Ability	127
6.2 Source and Modification	127
6.3 Indication	128
6.3.1 Ring-Down Counting	128
6.3.2 RMS Value	129
6.3.3 RMS and Energy	130
6.3.4 Energy Analysis	131
6.3.5 Event & Amplitude Distribution Analysis	131
6.3.6 Frequency Analysis	132
6.4 Interpretation	132
6.5 Applications	133
6.5.1 Flaw Location	133
6.5.2 Leak Detection	134
6.5.3 Other Applications	134
6.6 Work Problems	134
6.7 Graphs	135

CONTENTS

vii

7 Microwaves	145
7.1 introduction	145
7.1.1 Thickness of Metal Plates	146
7.2 Phase Measurements	146
7.3 Surface Cracks in Metals	147
7.4 Dielectric Plates	147
7.4.1 Reflection	147
7.5 Flaws	149
7.5.1 Voids	149
7.5.2 Delamination	149
7.5.3 Porosity	149
7.5.4 Inclusions	149
7.5.5 Material Properties	149
7.6 Graphs	150

List of Figures

1.1	The Electromagnetic Spectrum	10
1.2	Mechanical Vibrations and Sound Spectrum	11
2.1	The Pulse Echo Technique	34
2.2	Longitudinal Wave	35
2.3	Transverse (Shear) Wave	35
2.4	Rayleigh (Surface) Wave	36
2.5	Near and Far Fields	37
2.6	Beam Spread	38
2.7	Beam Pattern, (top: $\lambda = \pi d/5$)	39
2.8	Normal Beam Techniques	40
2.9	Transmission Technique	41
2.10	Angle Beam Technique	42
2.11	Longitudinal, Transverse and Surface Waves in a Wedge	43
2.12	Bubbler and Wheel Techniques	44
2.13	Water Immersion Technique	45
2.14	A-Scan	46
2.15	B-Scan	47
2.16	C-Scan	48
2.17	Nodes Technique	49
2.18	Weld Inspection with Node Technique	50
2.19	Pipe Inspection	51
2.20	Surface Inspection	52
3.1	Magnetic Poles	64
3.2	Hysteresis Curve	65
3.3	Hysteresis for High Retention (Top) and Poor Retention (Bottom) of Magnetic Fields	66
3.4	Rectified Current	67
3.5	Circular Fields	68

LIST OF FIGURES

3.6	Longitudinal Fields	69
3.7	Prod Method	70
3.8	Yoke Method	71
3.9	Demagnetization	72
4.1	Eddy Current	83
4.2	Single Coils	84
4.3	Dual Coils	85
4.4	Differential Coils	86
4.5	Multiple Coils	87
4.6	Equivalent Circuit	88
4.7	Current and Voltage Through Inductance	89
4.8	Voltage Components in Inductance	90
4.9	Impedance Diagram	91
4.10	Phasor Diagram	92
4.11	Impedance Display on Oscilloscope	93
4.12	Impedance Plane (Differential Testing)	94
4.13	Oscilloscope Presentation for Tube Inspection	95
4.14	Schmidt's Experiment	96
4.15	A Remote Field Inspection System	97
5.1	Radiography	110
5.2	X-Ray Tube	111
5.3	Photon Interactions	112
5.4	X-Ray Energy Spectrum	113
5.5	Effect of Voltage on X-Ray Energy Spectrum	114
5.6	Effect of Voltage on Penetrability	115
5.7	Voltage Required for Steel	116
5.8	Exposure for Steel	117
5.9	Exposure for Aluminium	118
5.10	A Gamma-Ray Devices	119
5.11	Ir-192 Exposure for Steel	120
5.12	Film Characteristic Curve	121
5.13	Effect of Exposure Direction on Geometry	122
5.14	Penumbra	123
5.15	Penetrometer	124
6.1	Kaiser Effect	136
6.2	Amplitude and Duration of AE Signal	137
6.3	Idealized AE Signal	138

LIST OF FIGURES

xi

6.4	Burst (Top) and Continuous Emissions (Bottom)	139
6.5	Measurement in Time and Frequency Domains	140
6.6	Count vs. Energy Analysis	141
6.7	Determination of Position	142
6.8	Leak Detection	143
7.1	Amplitude Method for Thickness Measurement	151
7.2	Phase-Shift Method for Thickness Measurement	152
7.3	Air-to-Dielectric Reflection	153
7.4	Dielectric-to-Air Reflection	154
7.5	Electrical Thickness vs. Reflection and Transmission coefficients	155
7.6	Phase-Shift vs. Electrical Thickness	156

B i b l i o g r a p h y

- [1] L. Cartz, Nondestructive Testing, ASM Int., Materials Park, OH, 1995.
(ON RESERVE IN ENG. LIBRARY)
- [2] D. E. Bray and D. McBride, Nondestructive Testing Techniques, John Wiley & Sons, New York, 1992. (ON RESERVE IN ENG. LIBRARY)
- [3] D. E. Bray and R. K. Stanley, Nondestructive Evaluation, A Tool for Design, Manufacturing, and Service, McGraw-Hill, New York, 1989. (ON RESERVE IN ENG. LIBRARY)
- [4] R.V. Williams, Acoustic Emission, Adam Hilger, Bristol, 1980.
- [5] (ON RESERVE IN ENG. LIBRARY) J. R. Matthews, Ed., Acoustic Emission, Gordon and Breach, 1983. (ON RESERVE IN ENG. LIBRARY)
- [6] J. Krautkramer and H. Krautkramer, Ultrasonic Testing of Materials, Springer-Verlag, Berlin, 1983. (ON RESERVE IN ENG. LIBRARY)
- [7] A. J. Bahr, Microwave Nondestructive Testing Methods, Gordon and Breach, New York, 1982. (ON RESERVE IN ENG. LIBRARY)
- [8] H. L. Libby, Introduction to Electromagnetic Nondestructive Test Methods, Wiley-Interscience, New York, 1971.
- [9] M.G. Silk, et al., The Reliability of Non-destructive Inspection, Adam Hilger, Bristol, 1987.
- [10] J. J. Burke, and V. Weiss, Eds., Nondestructive Evaluation of Materials, Plenum Press, New York, 1976.
- [11] P. Holler, Ed., New Procedures in Nondestructive Testing, Springer-Verlag, 1983.

BIBLIOGRAPHY

- [12] H.S. Lew, Ed., Nondestructive Testing, American Concrete Institute, Detroit, 1988.
- [13] R. C. McMaster, Ed., Nondestructive Testing Handbook, Ronald Press, New York, 1959.
- [14] Int. Advances in Nondestructive Testing, W. G. McGonnagle, Ed., Gordon and Breach, New York. (Periodical)
- [15] Materials Evaluation. (Periodical)
- [16] British J. Nondestructive Testing. (Periodical)
- [17] Non-destructive Testing Int. (Periodical)
- [18] J. Testing and Evaluation. (Periodical)
- [19] Non-Destructive Testing. (Periodical)
- [20] Soviet J. Nondestructive Testing. (Periodical)
- [21] Research Techniques in Nondestructive Testing; Academic, New York. (Periodical)