

Contents

Introduction	xi
Figure Credits	xv
Colour Section	xvii
1 Overview of Nondestructive Evaluation (NDE) Using Infrared Thermography	1
1.1 General Considerations	1
1.1.1 Short History of the Infrared	1
1.1.2 Various Instruments for Temperature Measurement	2
1.2 Active and Passive Approaches in TNDE	3
1.2.1 Passive Approach	3
1.2.2 Active Approach	6
1.3 New Materials	11
1.3.1 General Considerations	11
1.3.2 NDE Techniques for New Materials	12
1.3.3 Bonded Assemblies	14
1.3.4 Graphite Epoxy Structures	15
1.4 Detectors for Infrared Imaging	16
1.4.1 Thermal Detectors and Cameras	17
1.4.2 Photonic Detectors and Cameras	18
1.5 TNDE: Pros and Cons	21
2 Theoretical Aspects	23
2.1 Radiometry	23
2.2 Heat Transfer Modelling	29
2.2.1 Analytical Approach	29
2.2.2 Finite Difference Modelling	30
3 Experimental Apparatus	39
3.1 Description of the System and Intended Use	39
3.1.1 Infrared Cameras and Infrared Images	40
3.1.2 Selection of an Operating Wavelength Band	44

3.1.3	Acquisition and Analysis Equipment	45
3.1.4	Signal Recording	54
3.1.5	Measurement Reproducibility	58
3.1.6	Example of Analysis for an Experimental Set-up	59
3.2	Acquisition Process: Signal Restoration	60
3.2.1	Image Degradation	60
3.2.2	Noise	63
3.3	System Calibration	67
4	External Thermal Stimulation: Methods and Image Processing	73
4.1	General Considerations	73
4.1.1	Automatic Versus Manual Inspection	74
4.1.2	False Colour Image Coding	74
4.1.3	Different Types of Materials	75
4.2	Study of Graphite Epoxy Composites: Procedures, Investigation, Processing	75
4.2.1	Impact Damage	75
4.2.2	Evaluation of Fibre Content in Graphite Epoxy Composites	76
4.2.3	Delaminations	77
4.3	Study of Aluminium Laminates: Procedures, Investigation, Processing	79
4.3.1	General Considerations	79
4.3.2	Static Configuration	80
4.3.3	Mobile Configuration	83
4.4	Automatic Defect Detection	86
4.4.1	General Considerations	86
4.4.2	Image Formation	88
4.4.3	Automatic Segmentation Algorithm	93
4.4.4	Results and Discussion	97
5	Internal Thermal Stimulation: Methods and Image Processing	101
5.1	General Considerations	101
5.2	Case Study I: Evaluation of Corrosion Damage to Pipes	102
5.3	Case Study II: Inspection of Jet Turbine Blades	104
5.3.1	Experimental Analysis	106
5.3.2	Thermal Signature Analysis	108
5.3.3	Discussion	112
6	Quantitative Analysis of Delaminations	113
6.1	General Considerations	113
6.2	The Inverse Problem	113
6.2.1	A Practical Numerical Approach	113
6.2.2	Normalized Variables	119
6.3	Experimental Procedure: Thermogram Processing	122
6.3.1	Thermal Contrast	123
6.3.2	Logarithmic Time Scale	123

6.3.3 Practical Computation of $C(t)$, C_{max} , $t_{c-1/2max}$, t_{c-max} , $t_{c-max1/2}$	128
6.3.4 Defect Shape Extraction	132
6.4 Discussion on the Quantitative Characterization Procedure	137
7 Inspection of Materials With Low Emissivity by Thermal Transfer Imaging	139
7.1 General Considerations	139
7.2 Thermal Transfer Imaging	141
7.3 Physical Behaviour of Thermal Transfer Imaging Technique	144
7.4 Experimental Results	145
8 Thermal Diffusivity Measurements of Materials	149
8.1 General Considerations	149
8.2 Classical Thermal Diffusivity Measurement Method	150
8.3 Diffusivity Measurement Method Based on the Laplace Transform	151
8.4 Diffusivity Measurement Method Based on Phase Measurement	152
9 Thermal Tomography	157
9.1 General Considerations	157
9.2 Method	158
9.3 Some Results	162
10 Thermal NDE of Nonplanar Surfaces	165
10.1 General Considerations	165
10.2 Principle of Surface Curvature Correction	166
11 Applications of Infrared Thermography to High Temperatures	171
11.1 Detection of Rolled-in Scale on Steel Sheets	171
11.2 Thermal Inspection of High Temperature Industrial Structures	175
Appendix A Computer Model	177
Appendix B Smoothing Routine	181
Appendix C Parabola Computation	185
Appendix D Higher Order Gradient Computation Based on the Roberts Gradient	187
References	189
Index	203