Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER
UNCLASSIFIED	510350

TITLE

NDE FOR THICK SECTION COMPOSITE LAMINATES

System Number:

Patron Number:

Requester:

Notes: Paper #7 contained in Parent Sysnum #510343

DSIS Use only:

Deliver to: DK

#510350 (7)

NDE for Thick Section Composite Laminates

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ABSTRACT

NDE of Thick Section, Laminated Composites

"The application of fiber-reinforced polymer matrix composites to U.S. Navy surface ships systems offers the potential for significant weight, cost and signature reductions."

Gagorik, Corrodo, and Kornbau
Proceedings of the 36th International SAMPE Symposium, April 1991

NDE of Thick Section, Laminated Composites

Current applications for composites on submarines and surface ships

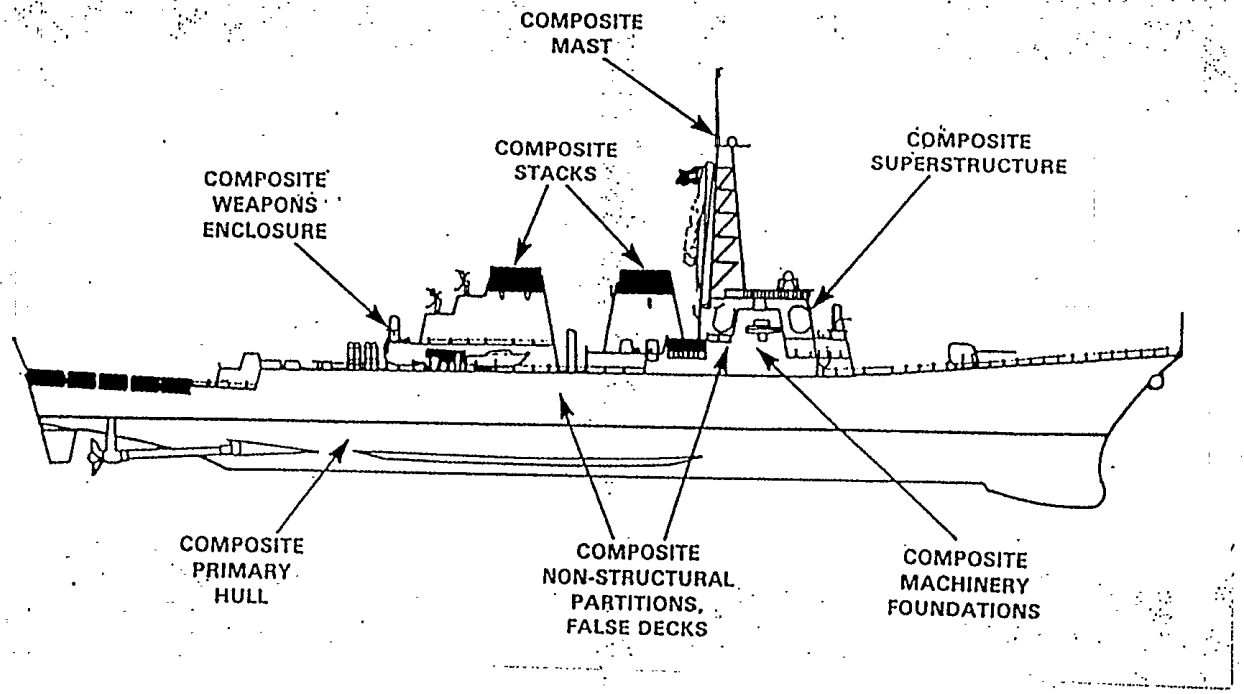
- submarine bow sonar domes
- towed array fairings
- sonar windows
- minehunter hulls
- other applications like seawater piping, pumps and ventilation ducting

Gagorik, Corrodo and Kornbau, SAMPE 1991

NDE of Thick Section, Laminated Composites

Potential Composite Ship Structures

Gagorik, Corrodo and Kornbau, SAMPE 1991



NDE of Thick Section, Laminated Composites

Challenges:

- anisotropic, inhomogeneous material
- many potential defect types (i.e., voids, delaminations, inclusions, resin variations, fiber breakage & wrinkles, etc.)
- no predominant failure mode
- presence of "acceptable flaws"
- manufacturing vs. service-induced defects
- large structures
- lack of defect and calibration standards

NDE of Thick Section, Laminated Composites

Classification of Defects in Thick Section Graphite Epoxy Test Blocks

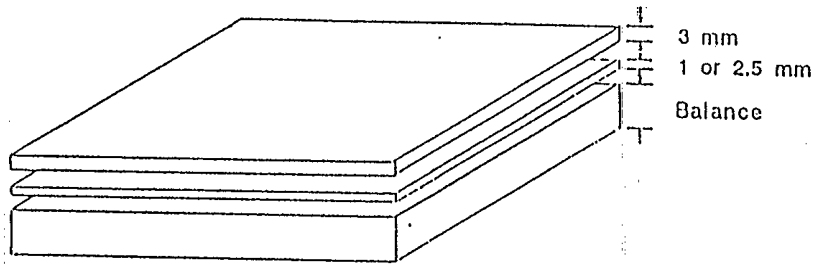
- Objective: To demonstrate the feasibility of using neural networks to classify defect types in thick section gr/ep material
- Approach:
  - construct thick section gr/ep test blocks with known defects at midply and near front surface
  - signal acquisition using immersion UT system
  - select features from power spectrum
  - defect classification using an artificial neural network

NDE of Thick Section, Laminated Composites

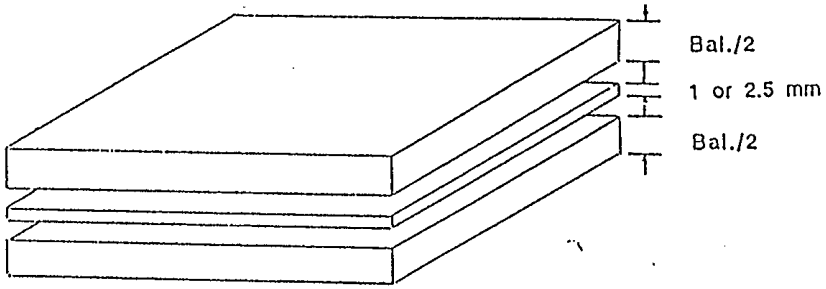
Classification of Defects in Thick Section Graphite Epoxy Test Blocks

- Status:
  - 8 specimens examined
  - 6 features from power spectrum selected
  - back propagation neural network analysis resulted in 91% classification accuracy for both training and test sets

CONSTRUCTION -



1/8 THICKNESS



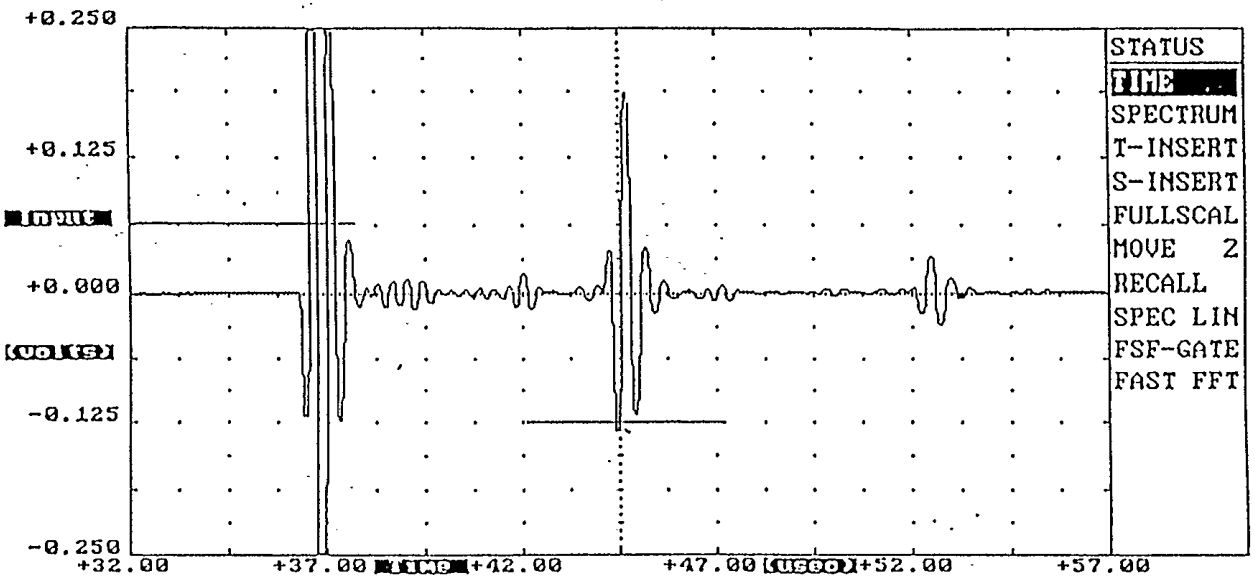
MIDPLANE

ID	PANEL DESCRIPTION	SUB-PANEL THICKNESS	SUB-PANEL PLACEMENT
A1	REFERENCE	NONE	
A2	REFERENCE	8-PLY	MIDPLANE, PLIES 92-99
B1	DELAMINATION	8-PLY	1/8 THICKNESS, PLIES 24-31
B2	DELAMINATION	8-PLY	MIDPLANE, PLIES 92-99
D1	POROSITY[1]	20-PLY	1/8 THICKNESS, PLIES 24-44
D2	POROSITY	20-PLY	MIDPLANE, PLIES 87-106
F1	CONTAMINATION[2]	8-PLY	1/8 THICKNESS, PLIES 24-31
F2	CONTAMINATION	8-PLY	MIDPLANE, PLIES 92-99

[1]Air
[2]Peel Ply

RESULTS - SAMPLE RF WAVEFORM

F2

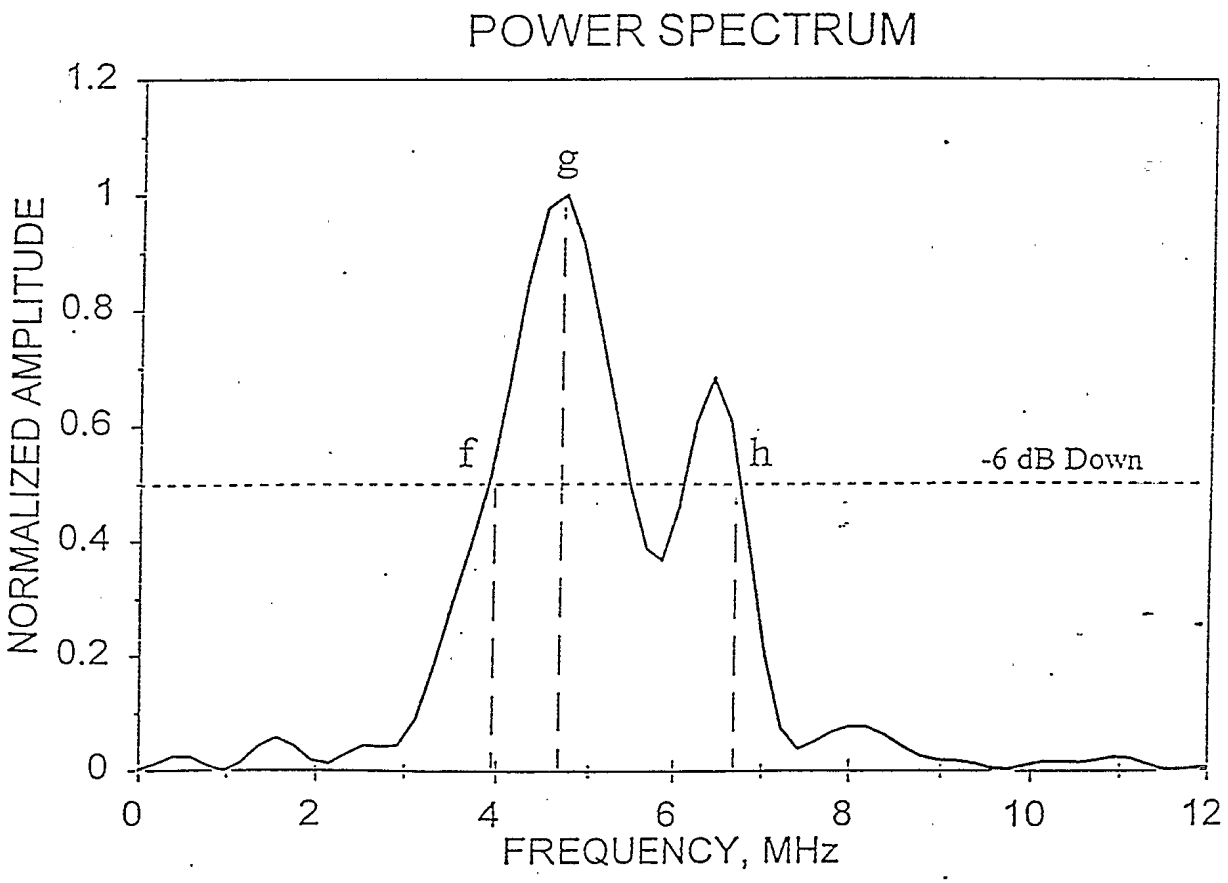


Disp Delay (us):	32.000	Horiz Scale Fac:	5	Sampling Rate:	100.000
Gate Start (us):	42.140	GateLength(pts):	512	Trigger Type:	FreRun+
Move Cursor:	25	FFT Length(pts):	512	DB Range:	24.000
# Wfms Averaged:	1	FFT Start(Mhz):	0.000	FFT End(Mhz):	50.000

COMPOSITE DEFECT CLASSIFICATION

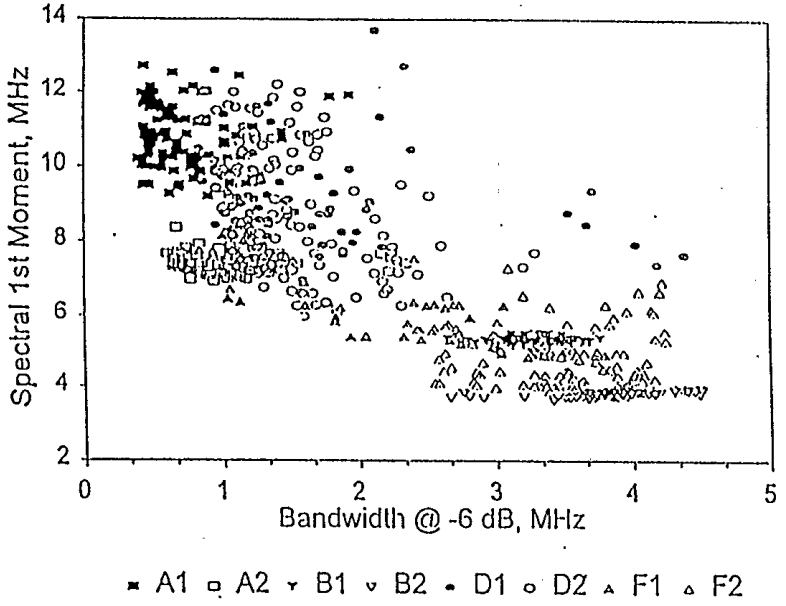
RESULTS - SELECTED FEATURES

PEAK FREQUENCY, MHz (g)
BANDWIDTH @ -6dB DOWN (h-f)
SPECTRAL SKEW @ -6dB DOWN (h-g)/(g-f)
SPECTRAL ENERGY @ 1.95 MHz
SPECTRAL FIRST MOMENT, MHz
SPECTRAL SECOND MOMENT, MHz

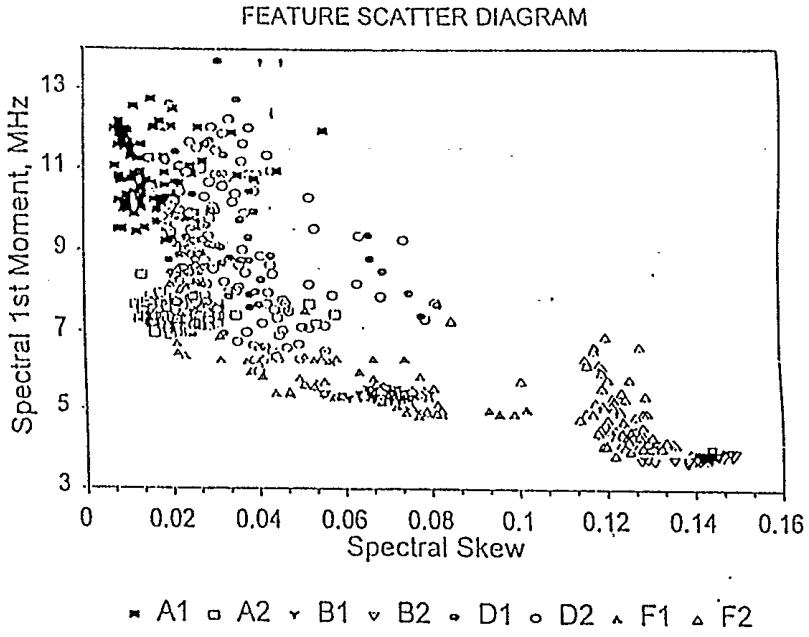


RESULTS - POWER SPECTRA FEATURES

FEATURE SCATTER DIAGRAM



FEATURE SCATTER DIAGRAM



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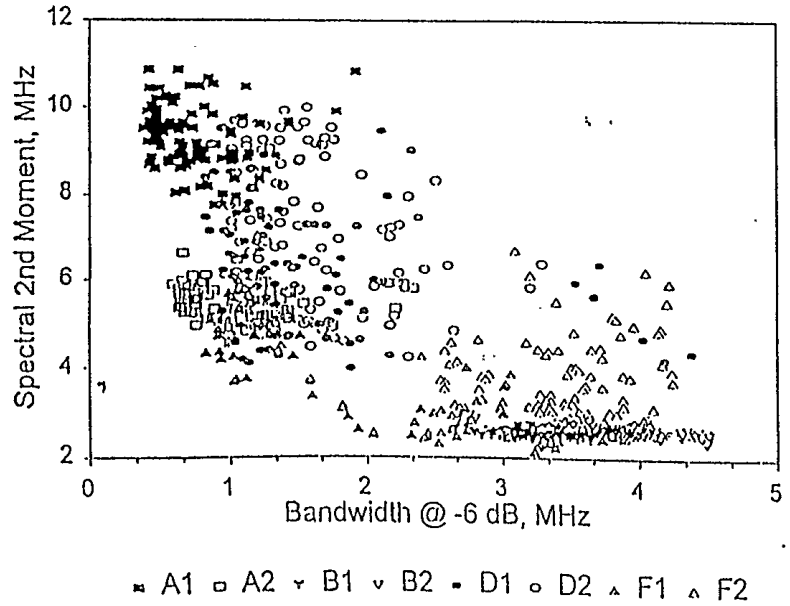

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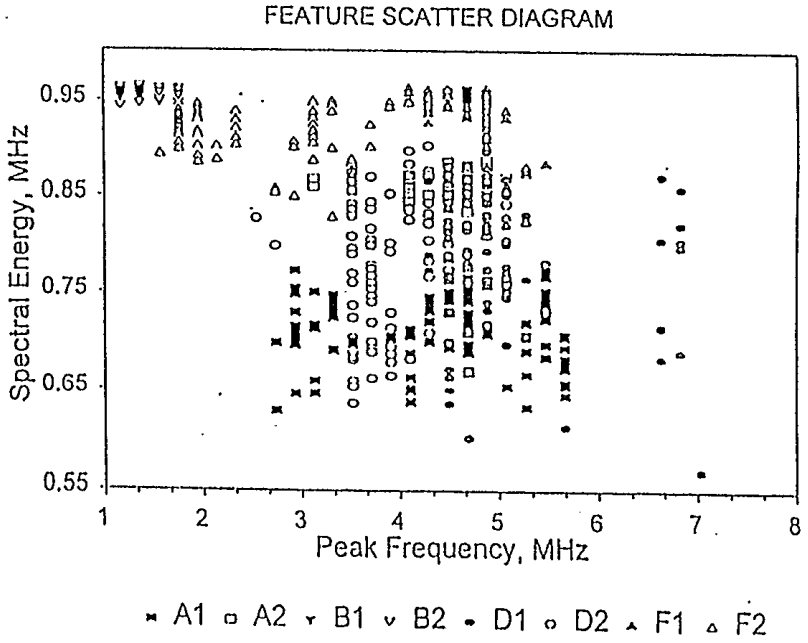


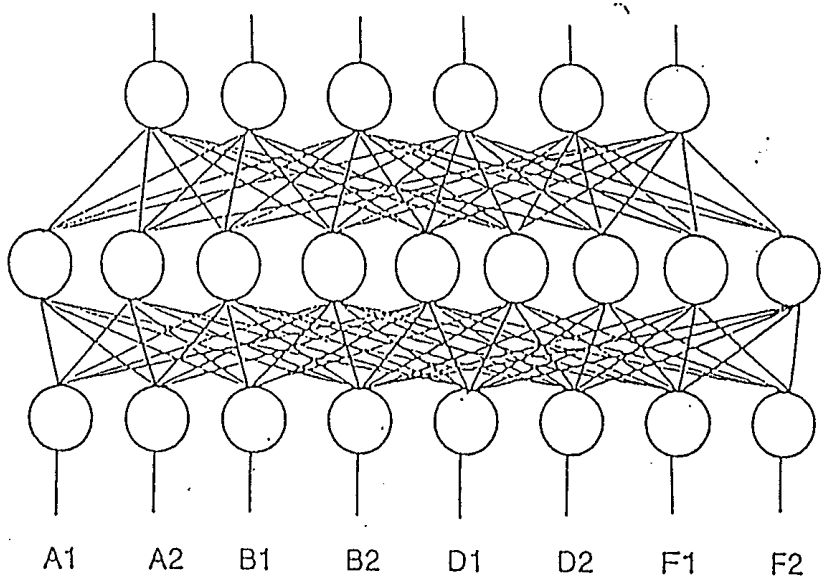
ARTIFICIAL NEURAL NETWORK -

- BACK PROPAGATION PARADIGM (NEURALWORKS PROFESSIONAL II)
- NORMALIZED CUMULATIVE DELTA LEARNING RULE
- HYPERBOLIC TANGENT TRANSFER FUNCTION
- 6 INPUT NEURONS, 9 NEURONS IN HIDDEN LAYER
- OBSERVATIONS IN CLASSIFICATION DATA (TEST SET RANDOMLY SELECTED BEFORE TRAINING)

CLASS	TRAIN	TEST
A1	90	10
A2	90	10
B1	90	10
B2	90	10
D1	90	10
D2	90	10
F1	69	9
F2	81	9
TOTAL	690	78

POWER SPECTRUM

INPUT FEATURES

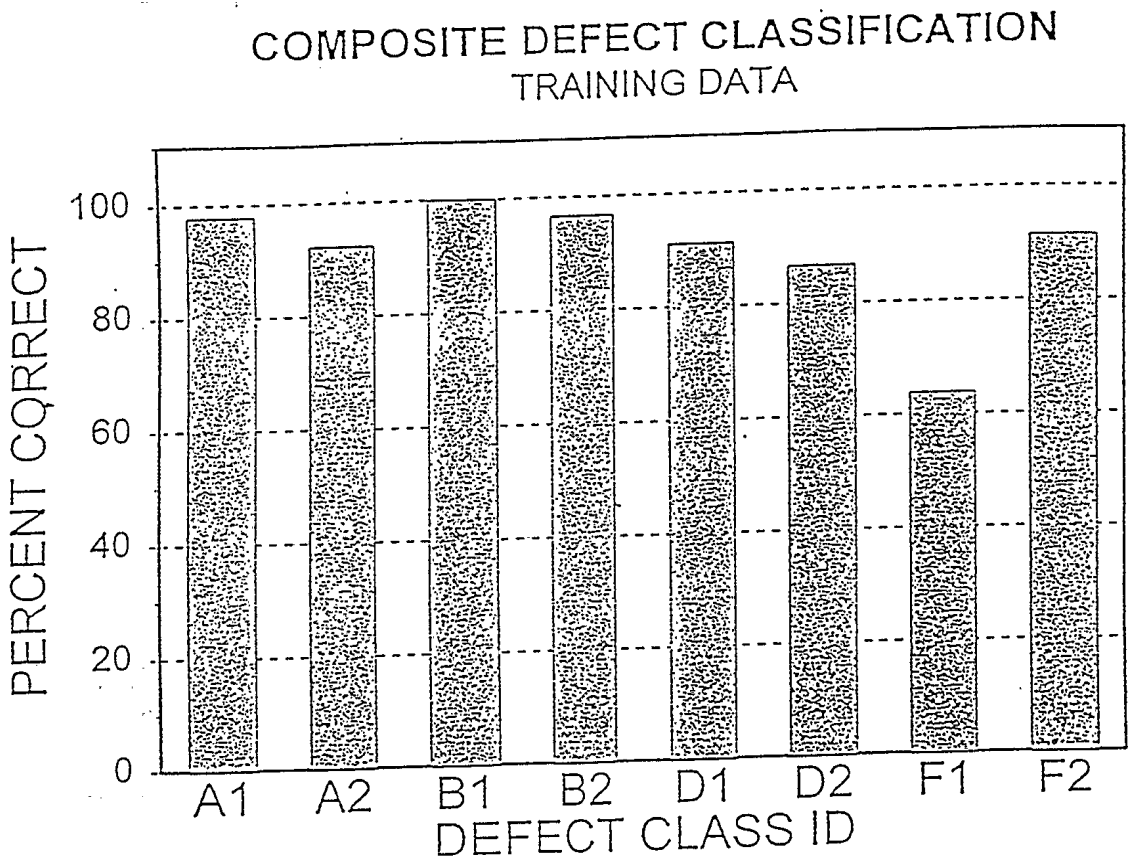


DEFECT CLASSIFICATION

- TRAINING ITERATIONS: 82,807

COMPOSITE DEFECT CLASSIFICATION

CLASSIFICATION RESULTS - TRAINING DATA



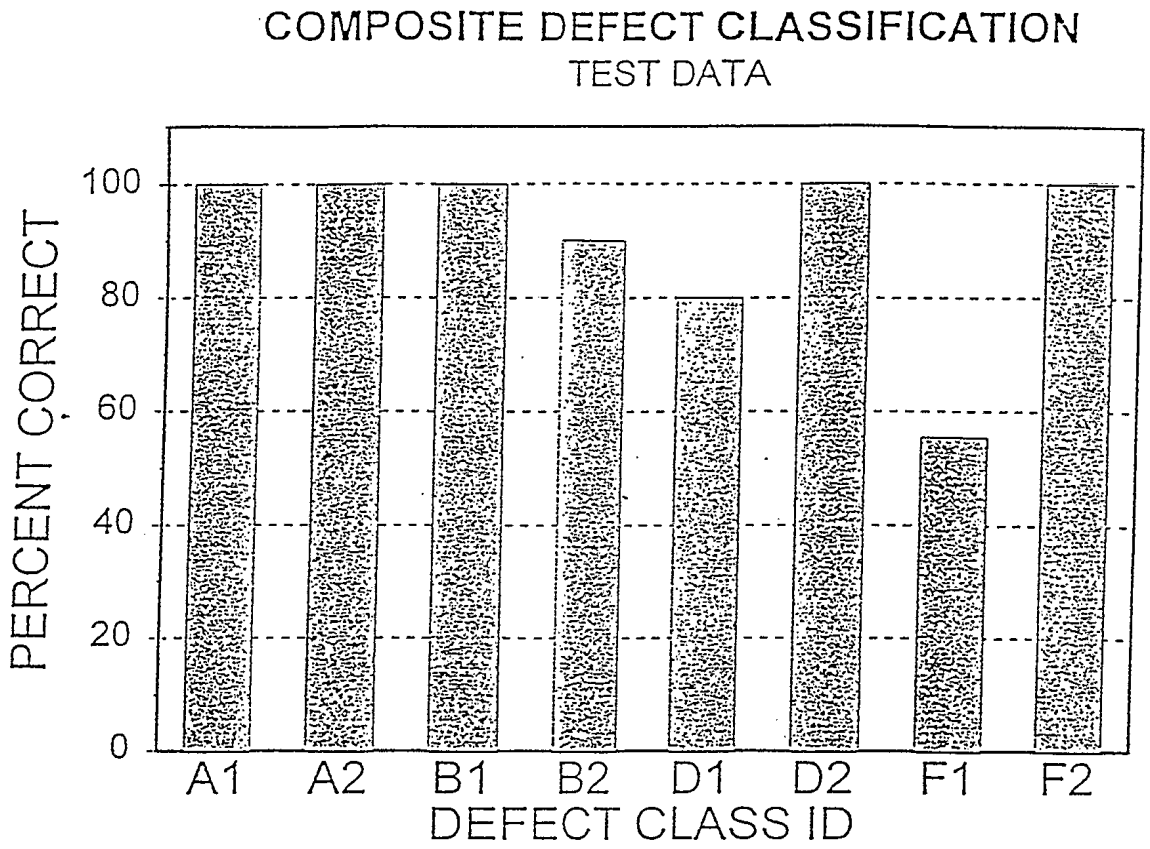
NEURAL NETWORK CLASSIFICATION*

		A1	A2	B1	B2	D1	D2	F1	F2	N	NOT CORRECT	CORRECT	PERCENT CORRECT
TRUE CLASS	A1	88	0	0	0	0	0	0	0	90	2	88	97.8
	A2	0	83	0	0	0	3	0	0	90	7	83	92.2
	B1	0	0	90	0	0	0	0	0	90	0	90	100.0
	B2	0	0	0	87	0	0	0	0	90	3	87	96.7
	D1	0	0	0	0	82	0	3	0	90	8	82	91.1
	D2	0	0	0	0	0	78	0	0	90	12	78	86.7
	F1	0	2	0	0	4	0	44	0	69	25	44	63.8
	F2	1	0	0	0	1	0	0	74	81	7	74	91.4
	TOTAL									690	64	626	90.72

*Class assignment for neuron output > 0.6.

COMPOSITE DEFECT CLASSIFICATION

CLASSIFICATION RESULTS - TEST DATA



NEURAL NETWORK CLASSIFICATION*

		A1	A2	B1	B2	D1	D2	F1	F2	N	NOT CORRECT	CORRECT	PERCENT CORRECT
	A1	10	0	0	0	0	0	0	0	10	0	10	100.0
	A2	0	10	0	0	0	0	0	0	10	0	10	100.0
	B1	0	0	10	0	0	0	0	0	10	0	10	100.0
TRUE	B2	0	0	0	9	0	0	0	0	10	1	9	90.0
CLASS	D1	0	0	0	0	8	0	0	0	10	2	8	80.0
	D2	0	0	0	0	0	10	0	0	10	0	10	100.0
	F1	0	0	1	0	0	0	5	0	9	4	5	55.6
	F2	0	0	0	0	0	0	0	9	9	0	9	100.0
	TOTAL									78	7	71	91.03

*Class assignment for neuron output > 0.6.

NDE of Thick Section, Laminated Composites

Thickness Gaging on a GRP Frame Structure

- Objective: To perform thickness gaging at approximately 175 locations on a GRP machinery cradle.
- Approach:
  - used Krautkramer Branson USD-10 with KB-Aerotech 1"diameter, 500 kHz delay line transducer
  - calibrations performed using:
    - for thicknesses up to 1", step wedge cut from cradle material
    - for thicknesses from 1" to 2", used accessible section of known "good" cradle material
  - variety of couplants used - Sonotech High Viscosity Soundclear was selected for this application

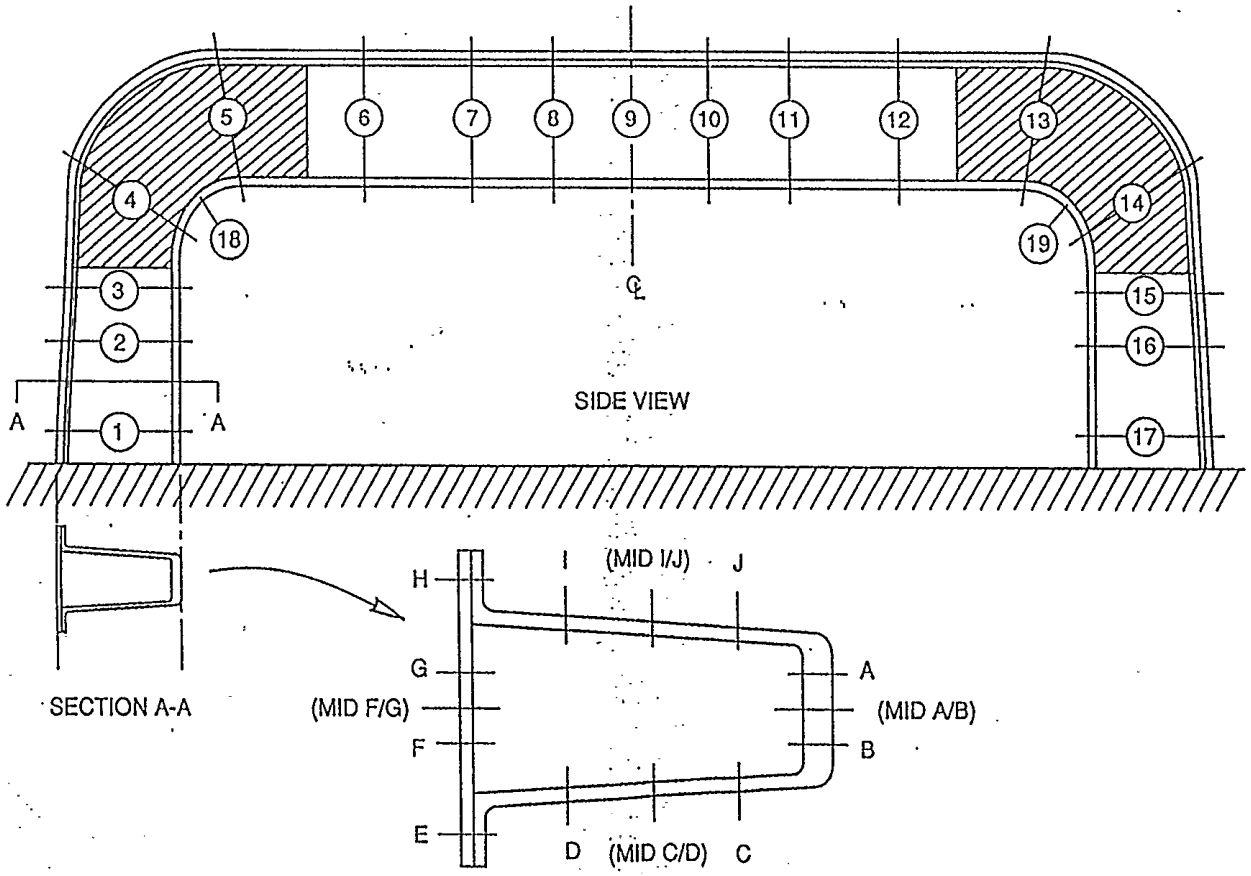
NDE of Thick Section, Laminated Composites

Thickness Gaging on a GRP Frame Structure

- Results:
  - at most locations, a backwall was readily discernable, thus permitting thickness measurement
  - A-scans contained obvious evidence of the layered nature of material
  - required approximately 10dB more gain to penetrate the 2" material (vs. 1" material)
  - inspection accuracy approximately +/- 1 mm
- Lessons Learned?????

NDE of Thick Section, Laminated Composites

Thickness Gaging on a GRP Frame Structure



NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- Objective: NDE of a very thick section (up to 8"), large area, GRP structure
- Approach:
  - identify specific locations to be monitored
  - for UT inspection:
    - independent measure of longitudinal velocity
    - transducer and equipment evaluation
    - calibration standard requirements & design
    - identify limitiations of inspection
  - Identify other potential inspection methods such as visual & microwave

NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- Independent measure of longitudinal velocity:
  - measurements using point-source/point receiver (PS/PR) ultrasonic technique.
  - two samples evaluated: a plate-like specimen measuring 1" in thickness, and a semi-circular "cut-out" measuring 5.5" thick.
  - resulting measured longitudinal velocities:
    - for 1" sample, V_L= 2.77mm/us
    - for 5.5" sample, V_L = 2.66 mm/us
  - amplitude of signal greatly influenced by thickness

NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- independent measure of longitudinal velocity
- longitudinal wave, pulse echo techniques used to measure time of flight through a 1" thick block of GRP material
- mechanical thickness measurements made at same locations with a micrometer
- longitudinal velocity calculated to be 2.66 +/-0.40 Km/s.

NDE of Thick Section, Laminated Composites

Inspection of a Large GRP Structure

- transducer and equipment evaluation
- evaluation of the wave penetration capability and influence of transducer frequency and diameter for a thick section of the GRP material (13 cm thick)
  - frequencies of 0.5 MHz or lower have better penetration capability
  - large diameter transducers (0.75" - 1") are more efficient and powerful for generating and receiving ultrasonic signals
  - dual element transducers provided higher SNR

NDE of Thick Section, Laminated Composites

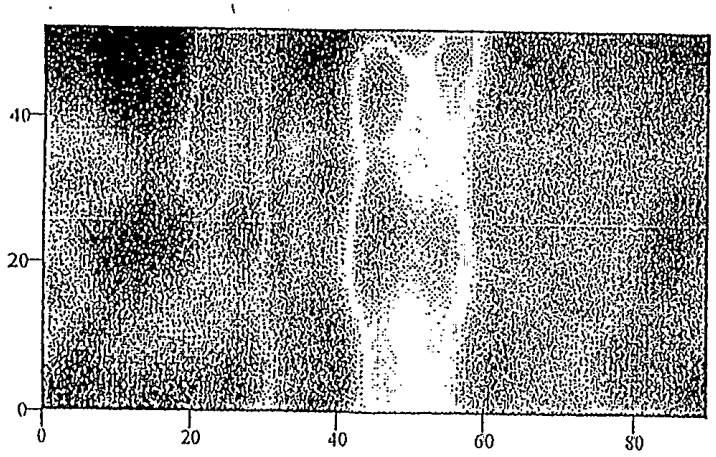
Inspection of a Large GRP Structure

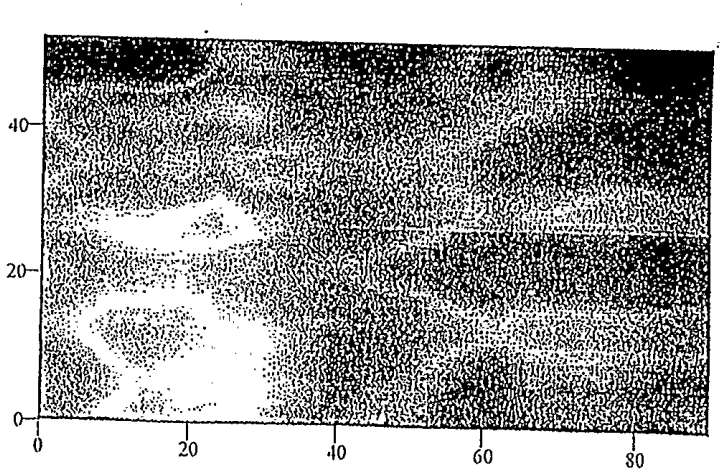
- transducer and equipment evaluation (cont.)
  - 3 types of UT instruments tried on actual structure with selected transducer
    - analog instrument - penetration depth ~ 0.5”
    - “older” digital instrument - penetration depth ~ 1-1/2”
    - “state-of-the-art” digital instrument - penetration depth ~ 3”

NDE of Thick Section, Laminated Composites

Microwave Inspection

Example: 10 GHz scan of 90 x 53 mm area with defect on a GRP panel. Left image obtained w/ standoff of 1.6 mm, right image w/ standoff of 14.25 mm. Left image shows inclusion; right shows variations in sample thickness.





NDE of Thick Section, Laminated Composites

Summary

- Composite usage increasing/many advantages to using composites for shipboard structures
- Many challenges associated with inspecting thick section composites
- Variety of techniques in NDE Toolbox
- Near-term requirement for inspecting a large GRP structure