NASA-CR-202096

A NEURAL NETWORK/ACOUSTIC EMISSION ANALYSIS OF IMPACT DAMAGED GRAPHITE/EPOXY PRESSURE VESSELS

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ABSTRACT:

Acoustic emission (AE) signal analysis has been used to measure the effects of impact damage on burst pressure in 5.75 inch diameter, inert propellant filled, filament wound pressure vessels. The AE data were collected from fifteen graphite/epoxy pressure vessels featuring five damage states and three resin systems. A burst pressure prediction model was developed by correlating the AE amplitude (frequency) distribution, generated during the first pressure ramp to 800 psig (approximately 25% of the average expected burst pressure for an undamaged vessel) to known burst pressures using a four layered back propagation neural network. The neural network, trained on three vessels from each resin system, was able to predict burst pressures with a worst case error of 5.7% for the entire fifteen bottle set.

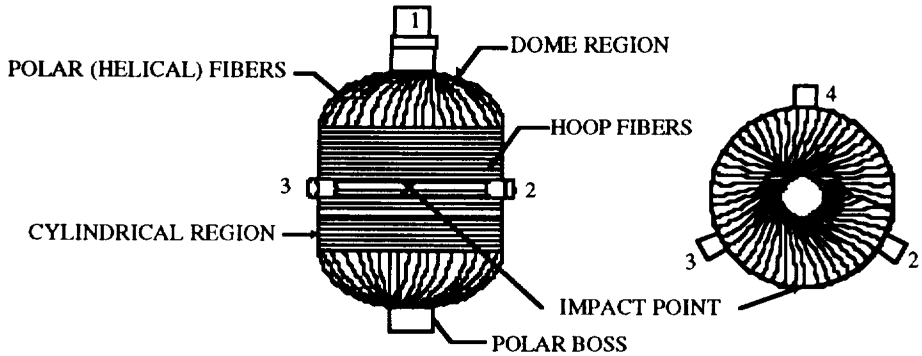
INTRODUCTION:

Impact damage, experienced in-service, is a problem that plagues the composites industry. Damage that may appear superficial can often times have a detrimental effect on the performance of a composite structure. Conventional NDE techniques typically can only map the locations and shapes of impact damage and are not able to quantify its effects on the structure. Acoustic-emission on the other hand, which records active flaw growth as the structure is loaded, can provide the means to measure the reduction in structural performance that has been produced by an impact load. This research effort demonstrates a method for quantitatively proof testing impact damaged composite pressure vessels at sub-critical loads through a neural network analysis of their AE amplitude distribution data.

APPARATUS AND PROCEDURE:

The vessels were all constructed from a Hercules IM-7 graphite fiber prepreg. Five vessels each were constructed using Hercules 3501-6 ATL, Hercules X8553-45 and Fiberite 977-2 prepreg epoxy resins. A calibrated dead weight drop fixture produced impact damage in the mid-hoop region of each vessel ranging from that which was barely visible to obvious fiber breakage. One vessel from each resin class was used as a control sample and left undamaged. The four remaining vessels were split into two equal groups and impacted with either a sharp or blunt tip. Two impact levels were used with each tip to produce a broad range of damage conditions. Electronic shearography and sub-pixel digital video image correlation techniques showed that the blunt tipped impactors generally produced a wide damaged zone with some localized delaminations while the sharp tip tended to break fibers at the impact point. A summary of these optical techniques is provided in the paper entitled; "Materials Characterization of Damage in Filament Wound Composite Pressure Vessels."

The pressure vessels' acoustic activities were collected during the hydroburst by a Physical Acoustics Corp. (PAC) SPARTAN AE system. A PAC R15I (150 kHz, 40 dB integral preamplifier) transducer was bonded with hot melt glue on the pipe plug used to seal the upper polar boss. Three PAC R15 (150 kHz resonant frequency) transducers were bonded symmetrically around the mid-hoop line and connected to external PAC 1220A preamplifiers (40 dB gain, 100 kHz to 300 kHz bandpass filter).



A 60 dB total gain and threshold were used to establish the system's sensitivity. The AE system's timing parameters defined the acoustic hits with a 30 µs peak detection time, 80 s hit detection time and a 300 s hit lock-out time. With these settings, lead breaks performed approximately two inches from each sensors produced amplitudes in the 80 dB range, verifying good sensor coupling.

Each bottle was first pressurized to 800 psig using a pressure ramp rate of 10 psi/sec (600 psi/min). The pressure was released after a two minute hold and then re-ramped back to a level of 750 psig, with a five minute hold after each 250 psi increase. The pressure was again reduced to zero before application of the final pressure ramp to failure. The AE amplitude distribution data collected through the first hold at 800 psig, along with the known burst pressures, were then tabulated for use in the neural network analysis.

A back propagation neural network was developed to model the effects of the impact damage on burst pressure using NeuralWorks Professional II/PLUS software, by NeuralWare, Inc. The amplitude distribution data from channel one, between 60 dB and 100 dB were introduced to the network through a 41 neuron input layer. The first of the two 13 neuron middle layers was fully connected by a series of weighting factors to the input layer, and then to each other. Burst pressure values were generated by a single output neuron that was fully weight connected to the second hidden layer. Finally, a bias neuron was weight connected to the hidden and output layer neurons to serve as a constant reference or offset value in the network. The interconnections' weighting factors ultimately served as the memory of a trained network by providing a multiplier between a preceding neuron's output value and an ensuing neuron's input value. Since the network was expected to search for subtle variations between the individual sample data sets a small learning coefficient, 0.001, and momentum, 0.1, were necessary. The epoch size was set at 3, to match the number of training set vectors, permitting an average of the entire training error to be used for each delta weight calculation. A hyperbolic tangent transfer function applied progressively smaller step sizes to the delta weights as the normalized training error decreased.

RESULTS:

The three resin systems were acoustically very different. The amount of AE activity recorded on channel 1 through the end of the first hold at 800 psig varied from an average of 420 hits for the 3501-6 resin, to 97 hits for the 977-2 resin, to only 11 hits for the 8553-45 resin. These results were expected, since the 977-2 and X8553-45 resin systems were formulated to be tougher than the brittle 3501-6 resin system, thereby providing a structure that could better redistribute stresses around stress concentrations rather than failing.

A summary of the neural network results is provided in the table below. Notice that by training on the amplitude distribution data collected from three vessels for each resin class, during the initial stages of loading, burst predictions were made with an average error of only 1.7 % (worst case error 5.7%) for the entire fifteen bottle set.

Resin Type	Bottle I.D.	Impact Status	Actual Burst (psig)	Predicted Burst (psig)	% Error

Hercules 3501-6	A003-004	None	2639	2605 [T]	-1.26
	C069-070	BT-5.0 ft-lbs	2279	2226	-2.30
	C077-078	BT-8.1 ft-lbs	2373	2381 [T]	0.37
	A013-014	ST-1.2 ft-lbs	2232	2359	5.70
	A017-018	ST-2.6 ft-lbs	1371*	1413 [T]	3.12
Fiberite 977-2	C115-116	None	3335	3308 [T]	-0.81
	C141-142	BT-5.0 ft-lbs	2786	2785 [T]	-0.01
	C117-118	BT-8.1 ft-lbs	3133	3113	-0.63
	C131-132	ST-1.2 ft-lbs	2996	3008 [T]	0.42
	C155-156	ST-2.6 ft-lbs	2804	2935	4.68
Hercules X8553-45	A025-026	None	3171	3132 [T]	-1.21
	A029-030	BT-5.0 ft-lbs	2302	2278	-1.00
	A047-048	BT-8.1 ft-lbs	2463	2466 [T]	0.13
	C087-088	ST-1.2 ft-lbs	2489	2551	2.51
	C093-094	ST-2.6 ft-lbs	1995	2028 [T]	1.67

BT = Blunt Tip (0.5 inch)   ST = Sharp Tip (1 mm)

* Dome Failure   [T] = Data used to train neural network

CONCLUSIONS:

- The result of this work shows that the effects of impact damage on the burst pressures of graphite/epoxy vessels can be made using a four layered back propagation neural network.

- This research effort provides a means for quantitatively proof testing composite pressure vessels that have experienced some form of impact damage in service.

ACKNOWLEDGMENTS:

Funding for this research effort was made available through the NASA Marshall Space Flight Center in cooperation with the University of Alabama in Huntsville and a NASA-JOVE research agreement between Embry-Riddle Aeronautical University and NASA MSFC.