VIBROTHERMOGRAPHIC NDE OF FIBEROUS COMPOSITES

S. S. Russell

Mechanical Engineering Dept.
University of South Carolina
Columbia, SC

S. S. Lin and E. G. Henneki, II

ESM Dept.
Virginia Tech.
Blacksburg, VA

INTRODUCTION

Vibrothermography refers to the process of mapping the temperatures on the surface of a component while the component is undergoing forced mechanical vibration. Damaged zones in a polymeric fiber reinforced composite more efficiently convert kinetic energy to heat. Hence, at certain frequencies, delaminations and other damage appear to a scanning infrared camera as hot zones.

This discussion of Vibrothermography will highlight the capabilities, advantages and limitations of using Vibrothermography as a nondestructive evaluation tool for fiber reinforced composites. Also, the frequency dependence of exciting delaminations will be examined within the framework of a Raleigh-Ritz model of a delamination. The predictions of this model are compared to laboratory results. However, first several trial investigations are presented.

TRIAL VIBROTHERMOGRAPHIC INSPECTIONS

General Experimental Method

For these investigations, an AGA680 Thermovision Infrared camera was used. The component undergoing inspection typically was bolted to a piezoelectric shaker, a Wilcoxon Research Model F7 and excited with a steady state vibration. Figure 1 was a schematic of the experimental equipment used to inspect a Gl-Ep component, the gate rotor geal. This particular part was radially distributed around an 8.6cm diameter hole. Two aluminum disks and a cap screw bolted this part to the shaker. Typically, the forced displacement from the shaker was oriented to excite plate bending mode vibration. The shaker was powered by a sweep oscillator, a power amplifier and a matching network. The frequency was swept slowly from 9kHz to 32kHz. The operator observes the display unit and held at frequencies which caused hot zones to appear. A 35-mm color still camera was used to record the Vibrothermograms.

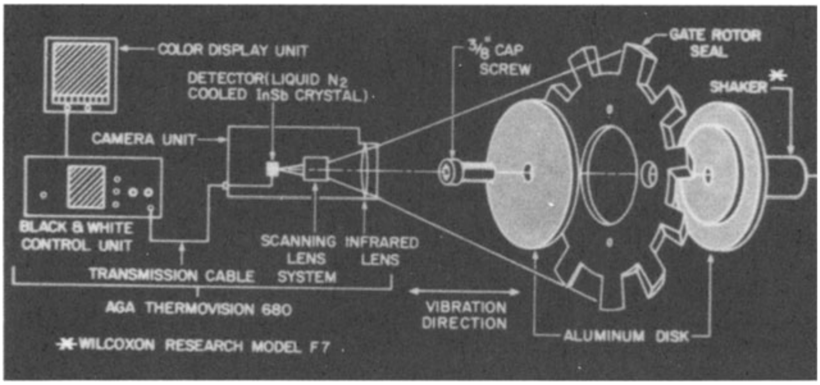

Figure 1. Schematic of Vibrothermographic Inspection

Gate Rotor Seal

The gate rotor seal investigated had been a component in a hydraulic pump, as seen in Fig. 2, the part with an "R" written on it. The bronze screw, in the center of the pump and also in the center of Fig. 2, failed damaging the glass-epoxy gate rotor seal. The seal was running in hydraul fluid, and the damaged zones were stained in the translucent seal. Hence the damaged areas were very apparent for each reference. The damage consisted primarily of delaminations with some surface chips and abrasion The damage was mapped onto a drawing of the part for reference.

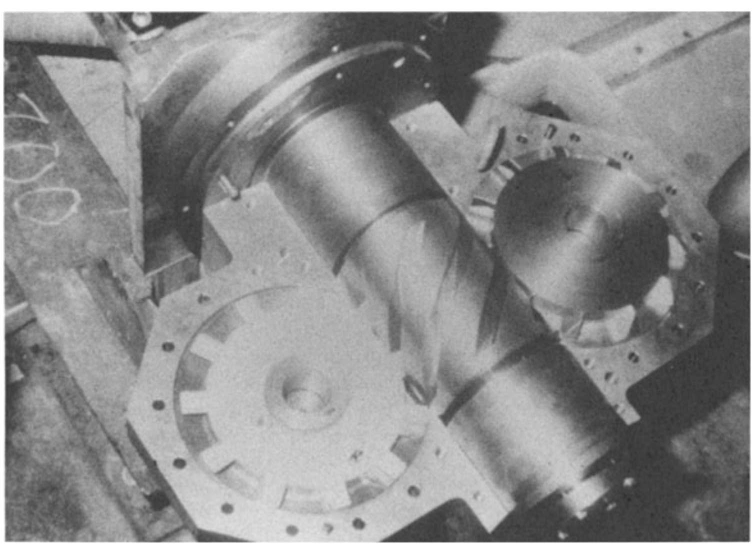

Figure 2. Gate Rotor Pump with Top Housing Removed

This seal was cut from a cross-ply glass-epoxy panel approximately 0.63cm thickness. The teeth had their edges cut with 45° bevels. Hence, this geometry presents a challenge for most nondestructive techniques.

A Vibrothermogram of one quadrant of the seal with excitation frequency of 13.6 kHz is presented as Fig. 3. Because of the inadequacy of this black and white copy of a color photograph, lettered arrows are used to indicate zones of interest. Zones "a", "b" and "c" are two delaminations and some surface gouges, respectively. The area "d" is a semicircle of higher temperature where heat from the shaker is being conducted by the aluminum plates into the gate rotor seal. A change of the excitation frequency caused different flaws to heat, but the union of all the hot spots indicates 75% of the damage observed by the staining.

<u>Impact Damage</u>

Among the panel examined after being impacted was a 30cm x 30cm hybrid panel whose construction consisted of a thin outer sheet of glass-epoxy fabric with three layers of glass polymide honeycomb and an inner sheet of graphite epoxy as shown in Fig. 4. The panel was attached to the shaker by an aluminum cone with a vacuum inside the cone to assure contact, Fig. 5. The weight of the panel was supported by the tape and the shaker was held in place by an aluminum column, see Fig. 5. The black tube carried the vacuum to the cone. The impact damage was minor and might have been overlooked in a visual inspection. However, carbon paper between the panel, an impactor established the damage location, indicated by arrows.

A Vibrothermogram of this panel is presented as Fig. 6. The shaker and vacuum tube are located in the center of this photo, with the impact damage indicated by arrows. Notice that zones of damage along the panels edge caused by the cutting of this panel from a larger panel are actively heating. This experiment illustrates the feasibility of inspecting a part or panel where access is allowed only to one side of the specimen through a temporary connection.

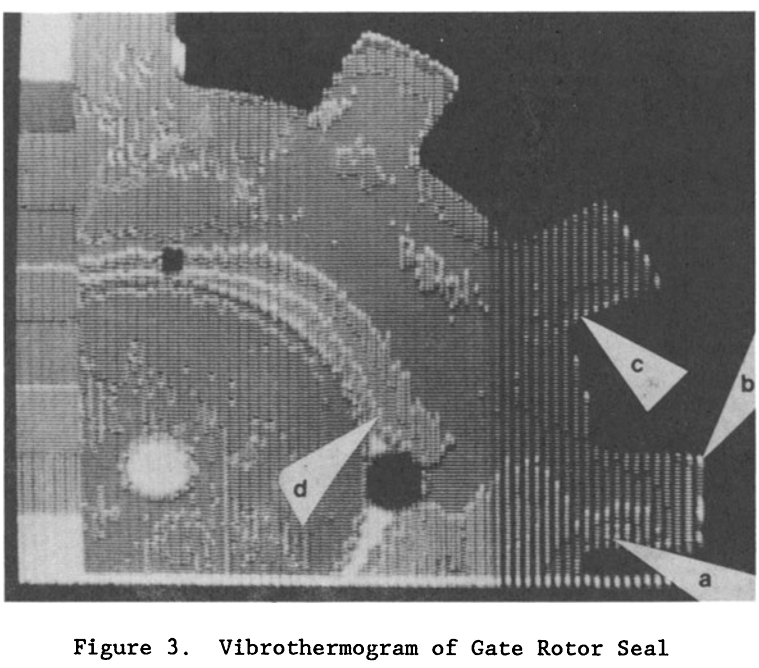

Figure 3. Vibrothermogram of Gate Rotor Seal

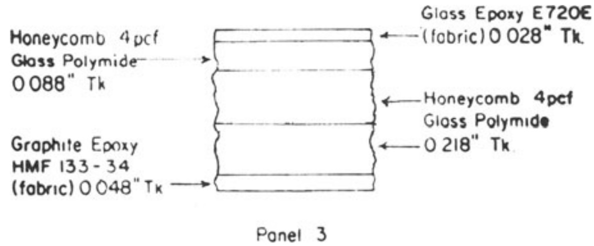

Figure 4. Construction of Hybrid Composite Panel

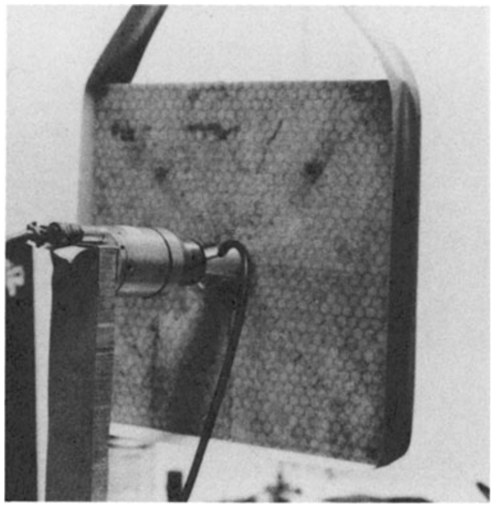

Figure 5. Shaker Attachment through Vacuum Cone to Hybrid Composite Panel

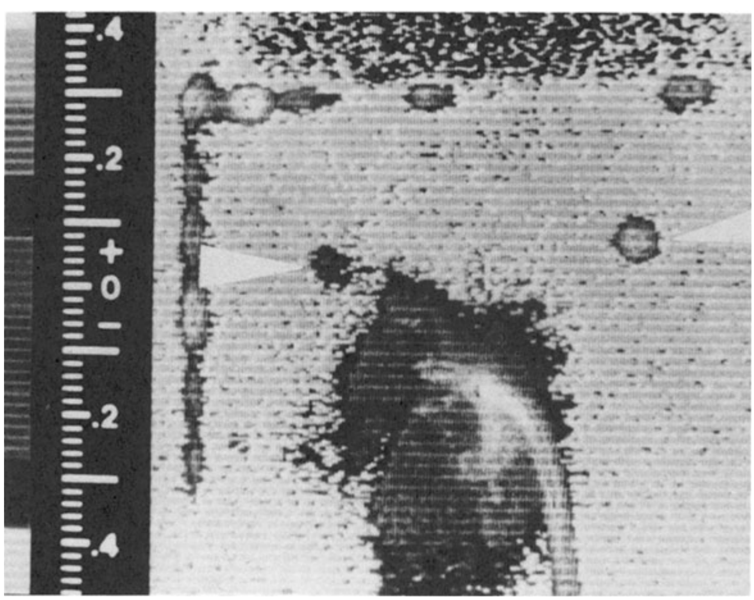

Figure 6. Vibrothermogram of Hybrid Composite Panel

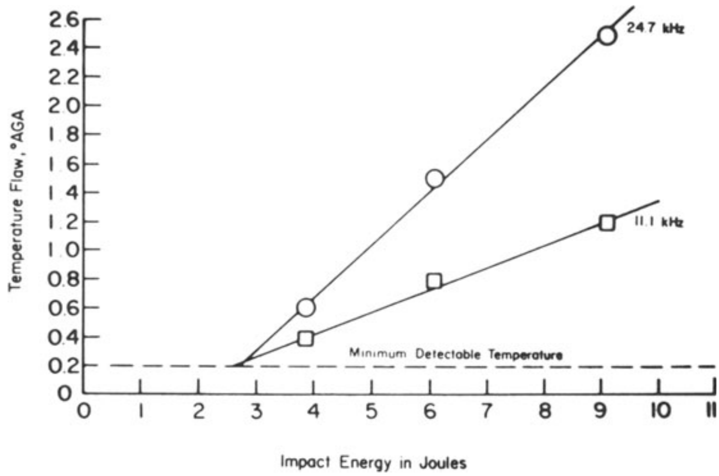

Fig. 7. Temperature of Center of Impact Damage versus the Energy of the Steel Sphere Impact

Quantization of Impact Damage

A 30-cm square panel of graphite epoxy with a lay-up of [0,90] was impacted by a cylindrical steel impactor in four different locations with the drop height different for each impact. The impact energies were 2, 3.8, 6 and 9 joules. The panel was then cut so that four coupons 2.54 cm x 1.52 cm each contained one of the impact sites in its center. This procedure of cutting coupons with the impact zone centered caused the coupons to have similar dynamic response. Hence, any difference observed during the Vibrothermographic inspection would be caused by the damage zone.

The beam resonance of these coupons occurred at 11.1 and 24.7 kHz, and at these frequencies the damage zones heated well. The steady-state temperature at the two resonant frequencies of the center of the impact zone was plotted as a function of the impact energy that caused the damage in Figure 7. The small damage zone was not detectable by Vibrothermography. However, an almost linear relationship existed between the impact energy and the temperature observed.

FREQUENCY DEPENDENCE

Two distinct types of frequency dependence have been observed during Vibrothermographic inspection of laminated composites. Either the part or component resonates such as the prior impacted coupons or the flaw resonates. The latter has been observed for delaminations. To investigate this phenomenon, delaminations were fabricated into a specimen prior to curing.

The delaminations were fabricated by folding a rectangle of mylar tape in half and sealing it with cellophane tape as shown in Figure 8. This package could then be placed between plies before lamination of a composite panel. By this method, the geometry of the delamination could be controlled.

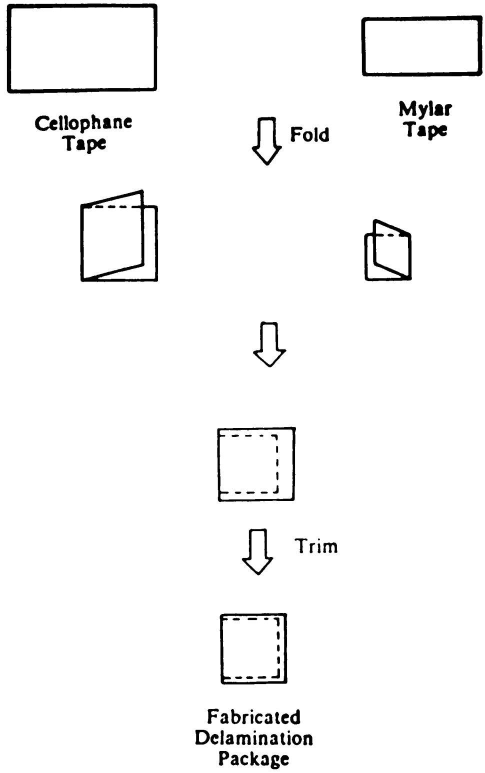

Fig. 8. Construction of Simulated Delamination for Inclusion in Panel during Lamination

A Rayleigh-Ritz analysis of plate vibration was used, to predict the resonant frequencies. The predicted frequencies by the Rayleigh-Ritz program and the frequencies that responded during vibrothermographic inspection for a [0] Gl-Ep panel corresponded well, as shown in Table 1. Also, because the flaw was displaced from the midplane of the panel each side of the delamination would resonate at different frequencies. If the heat conversion were due to the delamination surfaces hitting or sliding together, the thinner side should always be hotter. Since the 3-ply side the delamination sometimes was hotter than the 2-ply side, the conversion heat must be somewhat due to viscoelastic action of the thicker side.

CONCLUSIONS

Vibrothermography has been successfully used to evaluate damaged composite components. These components may contain impact damage, fabrication flaws or delaminations and the components may be of a complex geometry.

Vibrothermographic inspection can be performed on panels with access limited to a single side. The method is a true field technique that inspects large areas in a single test.

The dynamics of the vibration of the component or flaw are complex. However, if the vibration boundary value problem is defined, then the metl can be used to quantitatively determine the severity of impact damage.

Table 1. Comparison of the Heating Degrees on Each Side of [0] Glass-Epoxy Panel with Simulated Delamination D-34 on the 2-3 Ply Interface at Frequencies Which Local Resonance Occur

Predicated Frequencies (kHz)		Observed Frequencies (kHz)	Steady State Temperature (AGA)	
2-ply thickness	3-ply thickness		2-ply thickness	3-ply thickness
3.40		NA	NA	NA
	5.10	NA	NA	NA
6.17		NA	NA	NA
7.73		NA	NA	NA
	9.26	9.30	0.4-0.6	0.6
9.82		9.70	1.2	1.0
10.90		10.95	1.6	1.2
	11.61	11.60	1.4-1.6	1.6
13.88		13.80	1.4-1.6	1.4
14.56		14.50	1.0-1.2	1.0-1.2
	14.73	15.00	1.2-1.4	1.4-1.6
16.25		16.10	0.8-1.0	0.8
	16.35	16.60	1.2	1.2-1.4
17.39		18.00	1.2-1.4	1.0
19.63		19.70	0.6-0.8	0.6
	20.83	20.70	0.4-0.6	0.6