DEVELOPMENT OF A PULSE-ECHO ULTRASONIC SQUIRTER FOR DETECTION OF FIRST LAYER DELAMINATION IN COMPOSITE STRUCTURES

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INTRODUCTION

Inspection of advanced composite structures often requires the use of ultrasonic water squirter systems. These systems usually utilize through-transmission techniques to detect delaminations and other internal flaws. Through-transmission techniques are useful in detecting the presence of these flaws but cannot provide information as to the through-wall thickness location of the flaw. A pulse-echo squirter system can provide the capability to both detect and locate in the through-wall dimension the presence of delaminations. However, in the past, the turbulence usually generated in water squirter systems has made it impossible to do pulse-echo inspections. This was especially true for finding near-surface defects.

Many efforts have been undertaken to develop an ultrasonic squirter system which would provide a signal-to-noise level sufficient to allow the use of the pulse-echo technique and provide an acceptable near-surface resolution capability. Several marketed systems operate in the pulse-echo mode but are unable to achieve the near-surface resolution required at General Dynamics for composite part inspection. Industry's efforts to improve the performance of the squirter have primarily focused upon reduction of the turbulence in the water stream. These approaches have presented improvements over the more basic nozzles originally used but have not provided improvement sufficient to meet the needs of General Dynamics. Central to the issue is the need for a single-ply-depth near-surface resolution capability. This capability, coupled with the proper data acquisition system, will allow the inspection of composite materials with automated equipment without requiring the expensive and time-consuming high-resolution hand scan check of indications recorded using the through-transmission technique.

TECHNICAL DISCUSSION

An ultrasonic squirter was designed to have a water path of approximately 3 to 4 inches and a nozzle-to-part distance of approximately 1.5 inches, and to produce ultrasonic data identical to that obtained in the immersion mode.

The ultrasonic squirter design is shown in Fig. 1. The squirter consists of four major subcomponents: the nut, the body, the nozzle holder, and the nozzle nipple. The nut, body, and holder are made of brass, while the nozzle nipple is made of a silicon rubber compound. The nozzle material has an ultrasonic impedance similar to water, so that any ultrasonic sound striking this material will not be highly reflected. A mask ring within the body of the squirter is also composed of this material. The incoming water tubes are 1/4 inch inside diameter. Tests of different compounds of silicon rubber showed ultrasonic absorption levels of approximately 40 dB for normal incidence. The ultrasonic absorption for various compounds is shown in Fig. 2.

The squirter will accept transducers which have standard 3/8-inch diameter immersion transducer housings, i.e., 0.625 inch in diameter, 1.375 inches in length. The transducer can be unfocused or have a focal length in water up to 6 inches.

The fabricated squirter was tested with transducers that had frequencies of 10 and 25 MHz. In addition, the ultrasonic properties of the squirter were tested in successive steps from total immersion operation to total squirter operation. These steps included testing in the immersion mode; immersion mode with squirter housing; immersion mode with housing plus nozzle; immersion mode with complete squirter plus water flow; complete squirter plus flow mode with no immersion (with the squirter pointing downward); and complete squirter plus flow mode with no immersion (with the squirter pointing in the horizontal plane). The ultrasonic waveforms obtained from the squirter using a 10-MHz transducer during this process are shown in Fig. 3.

The closed water squirter system developed for this project utilized a Teel compact, self-priming pump, with a 5-micron inline water filter to decrease the water bubble formation. A flowmeter was placed in the water circuit to monitor the flowrates. To achieve proper operation of the squirter, 4 to 6 liters/minute of flow was required.

The capability to detect first layer defects was evaluated over a range of frequencies from 5 to 25 MHz. The results showed that the broadening of the 10-MHz waveform could be used to detect the near-surface defects at both the front surface and back surface, but the defect signals could not be totally time resolved. On the other hand, the first layer defect could be easily time resolved from the front surface using 25 MHz, but the attenuation of this frequency in graphite epoxy was so great that the backwall signal was barely observable. Therefore, 10-MHz transducers were used during the rest of the experimentation.

Using the squirter developed here along with conventional front-surface gate-following circuitry, we developed an inspection technique that would automatically provide a C-scan of the composite structure. The instrumentation is shown in Fig. 4. The output of the PR5600 receiver went into a Metrotek MD702 peak detector which has a gate function that can operate in the immersion front-surface following mode. The width and delay of the gate can be independently set. The output of the peak detector is a DC level which corresponds to the highest peak detected within the detection gate. In order to perform a C-scan, this output then goes

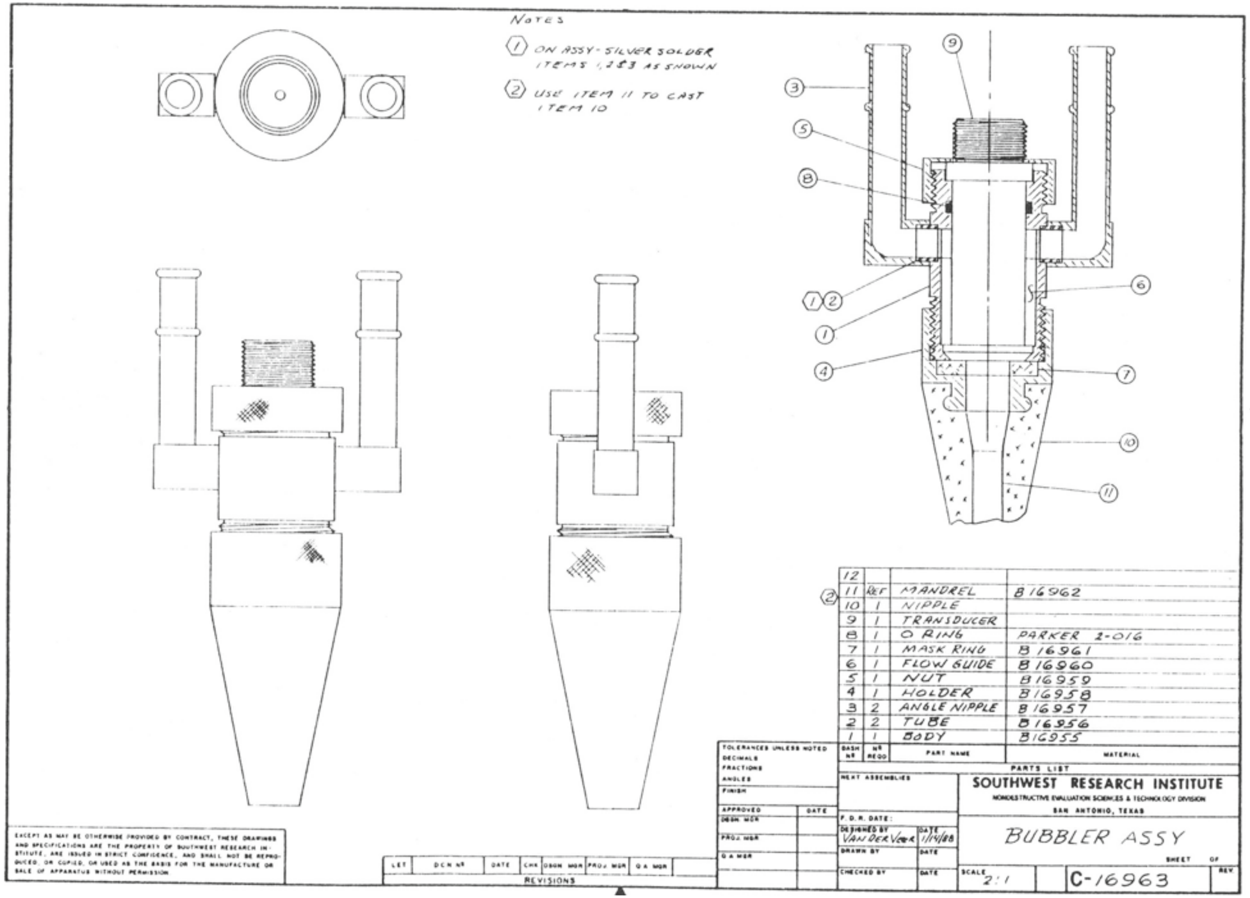

Fig. 1. Drawing illustrating the components of the ultrasonic squirter (annotated as the Bubbler). The nut, body, and nozzle holder are machined from brass, while the nozzle nipple and the washer in the nozzle holder are made from a mixture of silicon rubber.

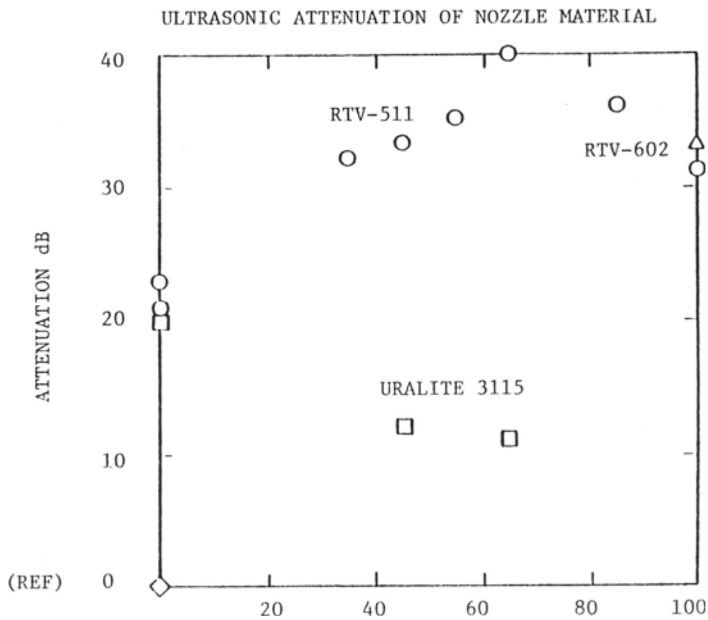

Fig. 2. Normal incidence ultrasonic attenuation data taken from various compounds of silicon rubber.

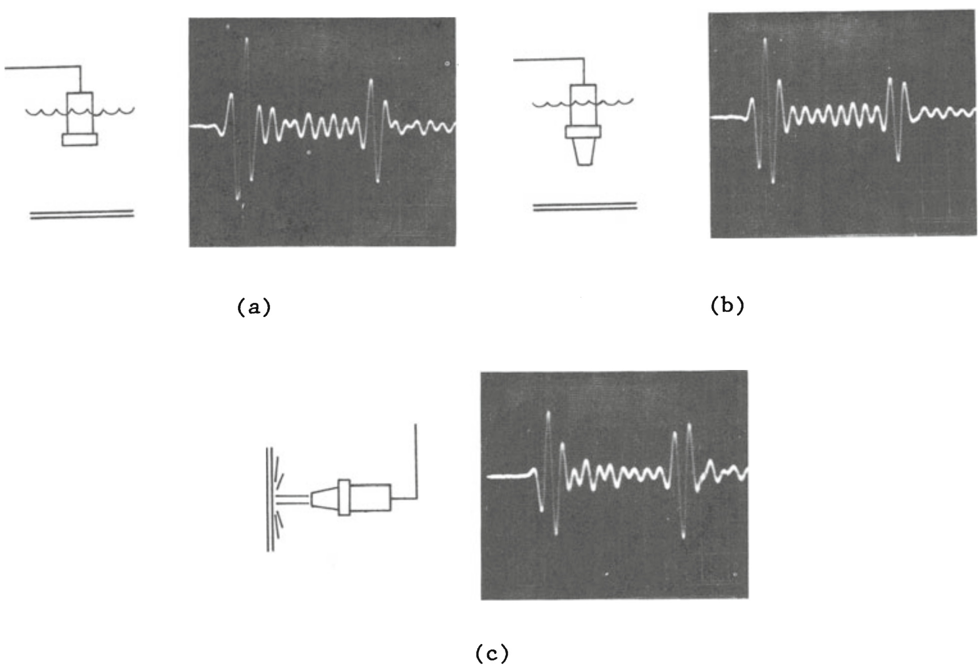

Fig. 3. Ultrasonic waveforms obtained from the General Dynamics supplied composite sample using the ultrasonic squirter (3a) in the immersion mode with squirter housing, (3b) in the immersion mode with the complete squirter including the nozzle, and (3c) in the squirter mode with the flow in the horizontal plane.

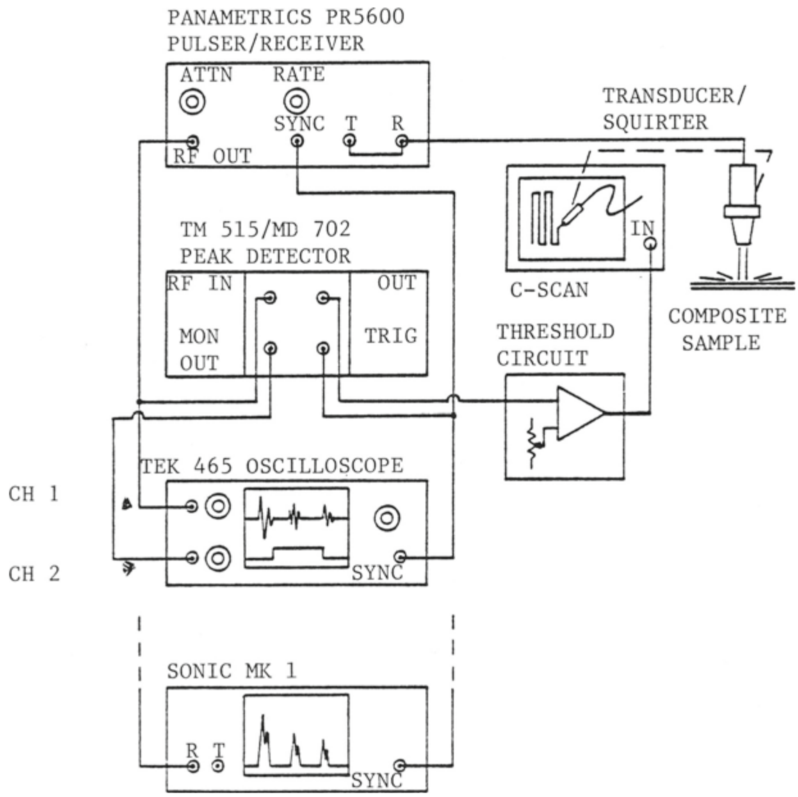

Fig. 4. Schematic view of the ultrasonic instrumentation used to collect ultrasonic C-scan data from the composite panels.

into a threshold circuit (developed previously by SwRI). The output of this threshold circuit is a TTL signal that then causes the pen of an Automation scan tank to write. The signal level that produces the threshold response can be varied in the threshold circuit.

The ultrasonic gates were set so that the C-scan system was triggered for signals that occurred between 300 nanoseconds after the front-surface reflection and 300 nanoseconds prior to the backwall reflection.

RESULTS

C-scans were taken on two samples, NTP007B and NTP007C. These samples had twelve delaminations in each panel. The defects were arranged in three rows of four defects. Each row had defects that were of the same diameter but different depths below the front surface. The diameters of the delamination defects were 0.125, 0.187, and 0.250 inch. In addition, each sample had a different surface roughness. The surface roughness for NTP007B was, on the average, 475 microinches RMS on the ID number side and 410 microinches RMS on the opposite side, and for sample NTP007C it was 28 microinches on the ID number side and 450 microinches on the opposite side.

The C-scan obtained from sample NTP007C is shown in Fig. 5. The raster scans were made at a pitch of 0.025 inch per scan. The C-scan for sample NTP007C showed that 10 of the 12 defects were detected. All

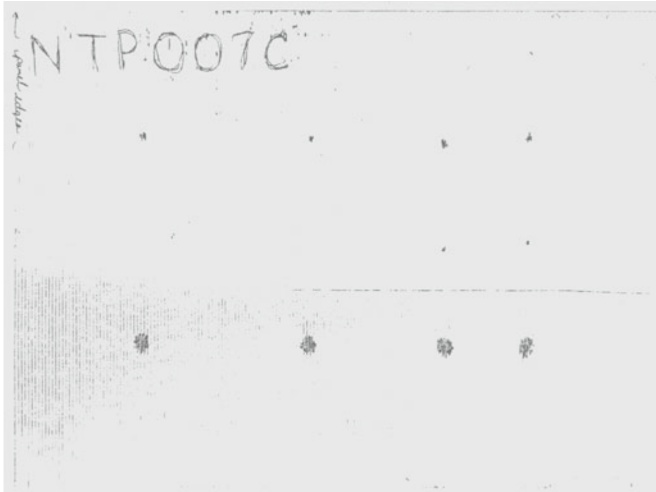

Fig. 5. Ultrasonic C-scan data obtained from composite panel NTP007C. Ten defects were detected (four were 0.250 inch in diameter, four were 0.187 inch in diameter, and two were 0.125 inch in diameter). The two that were not detected were the deeper 0.125-inch diameter defects. This panel had a surface roughness of approximately 28 microinches RMS which provided a high signal-to-noise ratio.

of the 0.25- and 0.187-inch delaminations were detected. The 0.125-inch diameter delaminations that were 0.006 and 0.030 inch below the surface were detected. However, the reason for not detecting the other 0.125-inch diameter delaminations is not understood, except that they were the deeper flaws.

The final test for this squirter was to demonstrate its function in a factory environment. In most instances, equipment used in the factory does not exhibit the same level of performance as specialized laboratory instrumentation. To confirm the applicability of this squirter, tests were performed on a 50-ply thick (approximately 1/4 inch) graphite-epoxy laminate, containing simulated delaminations at various depths through the panel. The simulated delaminations were manufactured by inserting coupons of GRAFOIL at various locations in the panel during the fabrication process. A drawing of this panel is shown in Fig. 6. A Sonic Mark III ultrasonic instrument, used in various areas of the factory since 1971, was selected as the ultrasonic instrument to be used with a Panametrics 10-MHz, 0.25-inch diameter, unfocused transducer. The water path was 3-5/8 inches, corresponding to a part-to-nozzle distance of 1-5/8 inches.

Fig. 7 shows the results of this experiment. All of the 1/2-inch and 1/4-inch diameter GRAFOIL inserts were detected using the squirter. The three 3/16-inch diameter inserts nearest the surface of the panel were also detected, while those inserts deeper into the part were not detected. None of the 1/8-inch diameter inserts were detected. It is important to note that no time-corrected gain (TCG) was used. If TCG were used, it would have most likely improved detection of the deeper 3/16-inch diameter defects.

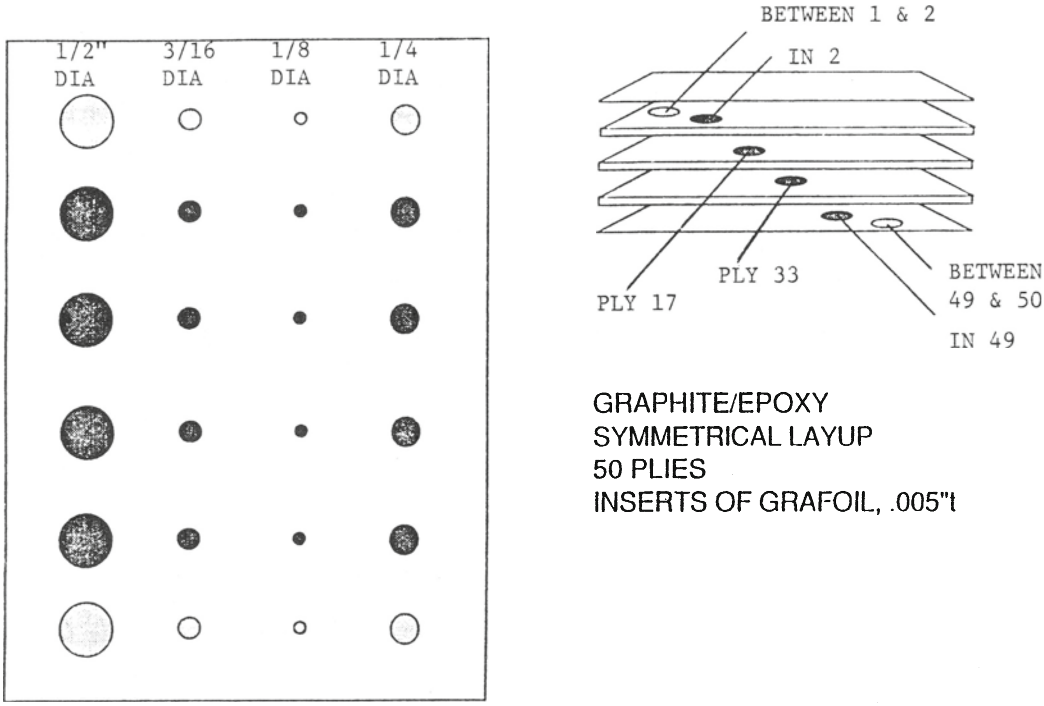

Fig. 6. Illustration of sizes and locations of GRAFOIL inserts used to simulate delamination defects in a 50-ply graphite-epoxy panel.

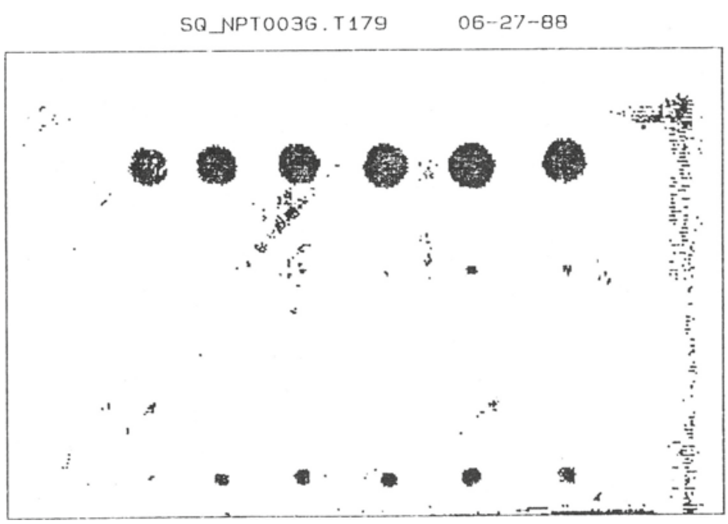

Fig. 7. C-scan results obtained from the 50-ply graphite-epoxy test panel.

The results obtained in this experiment demonstrate the applicability of the squirter to the production floor and to typical automated equipment. Achievement of this demonstrated level of resolution and sensitivity allows the squirter to be used in factory inspection systems, providing the ability to perform pulse-echo inspection in lieu of through-transmission. This is an important achievement, since certain foreign material inclusions in graphite-epoxy are extremely difficult, if not impossible, to detect using the through-transmission technique. This will also allow depth determinations to be made regarding detected indications, eliminating the need for the expensive hand scanning of indications for this determination.

CONCLUSION

A squirter was designed and developed that could simulate an immersion-mode, pulse-echo inspection using 10 to 25 MHz. The part-to-nozzle separation was approximately 1.5 inches with a total water path of approximately 3.25 inches. Tests conducted with the squirter illustrated that delamination-like defects as close to the surface as 0.006 inch and as small as 0.187 inch in diameter could be detected using automated ultrasonic instrumentation (both laboratory and factory floor instrumentation).

The squirter as presented here has allowed General Dynamics to meet their near-surface defect detection requirements using traditional, presently existing, ultrasonic instrumentation. Additional benefits have also been realized. The compactness of this squirter design will allow the inspection of more intricately contoured parts. The simplicity of the water system required for these demonstrations indicates that the need for very complex, highly regulated water systems may now be eliminated. Finally, the soft, "pop-off" nozzle provides collision protection for both the part and the inspection system, and affords simple replacement.