

## NEW TECHNOLOGY FROM ARPA/AFML

D. O. Thompson  
Science Center, Rockwell International  
Thousand Oaks, California 91360

and

H. M. Burte  
Air Force Materials Laboratory  
Wright-Patterson Air Force Base  
Dayton, Ohio 45433

D. O. Thompson (Science Center, Rockwell International): My purpose in this talk is to introduce the Poster Session that follows. We believe that most of the work presented in that session is ready for the next step of development. One of the key elements in this step is to find the "window" which can make use of these new pieces of technology. I truly appreciate the opportunity to hear the talks from the Air Force, Navy, and the Army which will help to identify some of these slots. I'd like to give a bit of our program philosophy that is important in this regard. On Wednesday, you heard some of the fundamentals of the ultrasonic work that we have been doing; work that has resulted in procedures which now are capable of producing numbers that characterize a defect. In achieving this capability, there are a number of improvements in various elements of the ultrasonic apparatus that have a useful identity of their own, i.e., they have a spinoff capability. Those are the elements that we wish to talk about this morning and to identify as having reached a proof-of-principle plateau, and, if you will, are ready now for the next question. In the context of Dr. Frank Kelley's remarks and the needs identified by the Tri-Services, we must now seek to put them into specific problems for evaluation. As indicated also by Dr. Kelley, this is a very important step in developing a technology flow within the DoD. However, research must continue in order that future results may also be harvested. With this background in mind, I'd like to introduce some of the topics that you'll see in the Poster Session that have been developed under ARPA/AFML sponsorship.

The first package of elements that we have pursued in achieving a quantitative capability is concerned with items providing options for improved ultrasonic reliability; fidelity, improved spatial resolution, processing, and so on. One of the posters you will see is by Professor R. M. White who has been developing ways to provide inverse filtering for ultrasonic NDE systems. He has adopted two approaches, the first being a SAW compensated device, and the second an approach utilizing CCD device technology. Key points that can be provided by this technique are summarized in Fig. 1. The second topic in this area has been developed by Prof. V. Newhouse and associates at Purdue. This work has not been a direct part of the current program, but funded under a separate ARPA/Air Force program. He has demonstrated a proof-of-principle utilizing deconvolution processes which permit another approach to the defect characterization problem

through signature comparison techniques. He utilizes both adaptive and minimization procedures which have to make some assumptions about the nature of the object. A summary of his work is provided in Fig. 2. A third topic in this group has been developed by Prof. Ken Lakin of the University of Southern California. One of the things that we have found in our efforts to develop quantitative information from ultrasonic return defect signals is the problem of not knowing really what the transducer does and what its characteristics are. He has developed a technique that allows one to do transducer modelling using the complex impedance and conversion efficiency to derive the acoustic output from measured electrical parameters, including a way to define and measure the effective gain of a transducer. Effective gain in this context is used in an overall sense. His system provides a convenient way to characterize the radiation patterns of the transducer and the displacements on any plane in the beam profile, including the surface of the transducer. This feature includes techniques to provide imaging of both the amplitude and phase response of the transducer plate. We believe that a standardized facility to look at transducers would go a long way toward providing ways to write better transducer specifications and improving ultrasonic reliability. This work is summarized in Fig. 3. Another topic in this group is a series of computer aided signal processing techniques, or software packages. A number of them are summarized in Fig. 4; these are available for use. These include procedures for transducer normalization, various windowing functions to improve the effect of signal-to-noise ratios, size estimation procedures, automatic classification of acoustic emission signals, and other topics. In addition to this work, which was specifically designed to aim at some of the quantitative problems associated with signal acquisition and sorting, the Adaptronics work is well known and very effective. It has produced a number of new results as a result of this program, although it existed well in advance of the start of the current effort. Finally, Fig. 5 gives a summary of a new concept for ultrasonic standards that has emerged from the quantitative scattering work in this program. The concept utilizes the sample preparation work done by Neil Paton, some of the theoretical work by Dick Cohen of the Science Center and Prof. Krumhansl and his associates at Cornell, and measurement procedures that have been developed by Bernie Tittmann. It is one of our beliefs that if we are going to make good quantitative ultrasonic measurements we must be

able to provide a system calibration. That is an essential and basic experimental concept. There are certain features in the suggested approaches that are quite different from standard flat-bottom hole approaches. Our work starts really with the recognition of the similarity between the solid state ultrasonic problem and the radar problem. Certain features that come out of this approach we believe to be advantageous and provide a way to separate unwanted transducer effects and materials variability from a true signal return. The concept introduces the utilization of theoretically developed signal returns. We believe this to be important, for it provides an operator with a set of expectation values for his calibration process, and thus, fills a gap in our current practice.

PROGRAMMABLE FILTER FOR ULTRASONIC NDE SYSTEMS

R. M. WHITE

INVERSE MATCHING FOR INDIVIDUAL TRANSDUCERS PROVIDES:

- COMPENSATION FOR AGING AND MATERIAL VARIATIONS
- INCREASED BANDWIDTH AND RESOLUTION
- NORMALIZATION OF FIELD TRANSDUCERS TO SAME OPERATING POINT

ACCOMPLISHED BY:

- PROGRAMMABLE TRANSVERSAL FILTER EMPLOYING COMMERCIAL CCDs
- BURST PROCESSOR - BETWEEN "MAIN BANG" SIGNALS

Figure 1. Programmable Filter for Ultrasonic NDE Systems.

DECONVOLUTION PROCESSING TO ENHANCE RESOLUTION

E. S. FURGASON, R. E. TWYMAN, AND V. L. NEWHOUSE

DECONVOLUTION PROCESSING ALLOWS:

- TARGET RECOGNITION THROUGH SIGNATURE COMPARISON

ACCOMPLISHED BY:

- UTILIZATION OF ADAPTIVE AND MINIMIZATION PROCEDURES WHICH MAKE ASSUMPTIONS ABOUT NATURE OF OBJECT

Figure 2. Deconvolution Processing to Enhance Resolution.

CHARACTERIZATION SYSTEM FOR NDE TRANSDUCERS

K. M. LAKIN

COMPOSITE RESULTS PROVIDE:

- UNIQUE TRANSDUCER CIRCUIT MODELING (YIELDS FREQUENCY, COMPLEX IMPEDANCE AND CONVERSION EFFICIENCY)
- DEFINITION AND MEASUREMENT OF EFFECTIVE GAIN OF TRANSDUCER
- CHARACTERIZATION OF FAR FIELD RADIATION PATTERNS (FRESNEL)
- IMAGING OF SURFACE DISPLACEMENT FIELDS (AMPLITUDE AND PHASE, NEAR-FIELD RESPONSE)

RESULTS HAVE BEEN OBTAINED UTILIZING AN INTEGRATED ACOUSTO-ELECTRICAL CHARACTERIZATION PROCEDURE.

Figure 3. Characterization System for NDE Transducers.

COMPUTER AIDED SIGNAL PROCESSING TECHNIQUES

R. K. ELSLEY

SOFTWARE PROCEDURES FOR ON-LINE SIGNAL PROCESSING INCLUDE:

- PROCEDURES FOR TRANSDUCER NORMALIZATION
- WINDOWING FUNCTIONS TO IMPROVE SN RATIO
- SIZE ESTIMATION OF SMALL DEFECTS
- AUTOMATED CLASSIFICATION OF AE SIGNALS

ACCOMPLISHED WITH MINICOMPUTERS WITH 32K MEMORY

Figure 4. Computer Aided Signal Processing Techniques.

NEW ULTRASONIC STANDARDS

B. R. TITTMANN AND N. E. PATON

QUANTITATIVE "RADAR RANGE EQUATION" APPROACH:

- PERMITS SEPARATION OF UNWANTED EFFECTS DUE TO TRANSDUCERS AND MATERIALS VARIABILITY
- FOCUSES ATTENTION ON REPRODUCIBLE SCATTERED ACOUSTIC POWER MEASUREMENTS
- PROVIDES ADDITIONAL INDEPENDENT VARIABLE (THEORETICAL SCATTERING CROSS-SECTION) FOR USE IN CALIBRATION PROCEDURE
- CAN BE ADAPTED TO BOTH PULSE-ECHO AND PITCH-CATCH MODES

ACCOMPLISHED BY:

- EMBEDDING SCATTERING TARGET IN A SOLID MEDIUM USING DIFFUSION BONDING OR ANALOGOUS TECHNIQUES
- TARGET IS THUS SIMILAR TO A SPHERE IN A WATER BATH WITH ADVANTAGES IN CONVENIENCE, PORTABILITY, AND APPLICATION TO SHEAR WAVE CALIBRATIONS

Figure 5. New Ultrasonic Standards.

Another part of the program that has turned out to be exceedingly rich in new thoughts and capabilities is that of the non-contact ultrasonic transducer (EMAT). Improvements made in this area by a number of authors are summarized in Fig. 6. Also shown in the Poster Session this morning are some applications that have been developed in parallel programs. One of these, sponsored by the American Gas Association, applies to the inspection of buried natural gas pipelines. Another one, sponsored by the Army, applies to the inspection of projectiles. A third one sponsored by EPRI pertains to the inspection of heat exchanger tubing. A fourth one, sponsored by Rockwell International, relates to the high temperature inspection of weldments.

#### OPTIMIZATION AND APPLICATION OF EMATs

R. B. THOMPSON, C. M. FORTUNKO, C. VASILE, G. ALERS, T. MORAN

##### PROVIDES CAPABILITY FOR NONCONTACT ULTRASONIC TRANSDUCTION:

- HIGH SPEED OPERATION (20 mph DEMONSTRATED)
- HIGH TEMPERATURE OPERATION (500F DEMONSTRATED)
- REMOTE CONTROL AND AUTOMATION APPLICATIONS
- GENERATION OF NEW WAVE TYPES SUCH AS HORIZONTAL SHEAR
- GENERATION OF CODED WAVEFORMS FOR RESOLUTION IMPROVEMENT
- GENERATION OF ELECTRONICALLY CONTROLLED ANGLE BEAMS
- RESIDUAL STRESS DETECTION IN FERROMAGNETIC MATERIALS

##### IN-PROGRESS APPLICATIONS:

- BURIED NATURAL GAS PIPELINES
- 155 mm ARTILLERY PROJECTILES
- STEAM GENERATOR TUBES
- HIGH TEMPERATURE WELDS

Figure 6. Optimization and Application of EMAT's.

Another poster presented in the sessions gives the results of work by Prof. Kino and his students at Stanford in ultrasonic imaging. This work represents a transfer of technology that they had developed for the medical field into the materials area. They've achieved a number of things in this area which are summarized in Fig. 7, including transmission images of epoxy bonded boron fiber reinforced laminates, with significant hundred-speed increases while maintaining a resolution comparable to that of the current C-scan systems, and have produced images with a variety of ultrasonic wave types; i.e., Rayleigh waves, Lamb waves, longitudinal and shear waves.

#### ULTRASONIC IMAGING SYSTEM

G. S. KINO, T. M. WAUGH, AND D. CORL

IMAGING OF FLAWS PROVIDES A RAPID INDICATION OF FLAW POSITION, SIZE, SHAPE AND ORIENTATION. HAVE OBTAINED:

- TRANSMISSION IMAGES OF EPOXY BONDED BORON FIBER REINFORCED LAMINATES WITH 100 FOLD SPEED INCREASE AND RESOLUTION COMPARABLE TO THAT OF MECHANICALLY SCANNED SYSTEMS
- FOCUSED REFLECTION IMAGES WITH RESOLUTION OF 2λ
  - RAYLEIGH WAVES
  - LAMB WAVES
  - LONGITUDINAL WAVES
  - SHEAR WAVES
- MEASUREMENTS OF LENGTHS OF CRACKS WHEN CRACKS NOT PARALLEL TO ARRAY BY DEFINING POSITION OF LINE SCATTERS AT ENDS

ACCOMPLISHED BY:

- ELECTRONICALLY SCANNED AND FOCUSED IMAGING DEVICES PRODUCING REAL TIME IMAGES

Figure 7. Ultrasonic Imaging System.

The adhesive bond work has demonstrated proof-of-principle for both cohesive and the adhesive characterization in simple systems. Further work is needed in the case of complex, two-phase adhesive systems. This work is summarized in Fig. 8.

#### STRENGTH MEASUREMENT OF ADHESIVE BONDS

P. L. FLYNN, G. A. ALERS, AND R. K. ELSLEY

PROVIDES PROCEDURE FOR:

- PREDICTING COHESIVE STRENGTH OF ADHESIVE MATERIAL WITHIN BOND LINE
- PREDICTING STRENGTH OF ADHESION AT METAL-TO-ADHESIVE INTERFACE

ACCOMPLISHED BY:

- SIGNAL ANALYSIS OF ULTRASONIC PULSES REFLECTED FROM ADHESIVELY BONDED STRUCTURES
- ESTABLISHING A THEORETICAL MODEL FOR INTERACTION OF ULTRASOUND WITH LAYERED MEDIA
- RAPID COMPARISON OF THEORY AND MEASUREMENTS IN A COMPUTER

Figure 8. Strength Measurement of Adhesive Bonds.

Finally, proof-of-principle has been demonstrated for the non-destructive measurement of moisture in composites. One of these methods is demonstrated in Fig. 9. This work is based upon a direct measurement of the effusion rates of moisture from a composite material. Using these results and measured diffusion coefficients, the inverse problem has been solved to yield a quantitative map of the water concentration profile as a function of depth in the material. From this, a strength profile can be obtained.

D. H. KAEUBLE

## PROVIDES ANALYTIC CAPABILITY TO ASSESS:

- DIRECTIONAL OR AVERAGED MOISTURE DIFFUSION COEFFICIENTS
- WATER CONCENTRATION VALUES AND CONCENTRATION PROFILES
- MICROSTRUCTURE AND STRENGTH DEGRADATION DUE TO WATER ABSORPTION

## ACCOMPLISHED BY:

- MEASUREMENT OF EFFUSION RATES
- INVERSION OF DIFFUSION EQUATION TO OBTAIN CONCENTRATION PROFILES

Figure 9. Moisture Diffusion Analysis (MDA) for Composites.

H. M. Burte (AFML): I want to identify two areas for additional comment that particularly intrigue me. One of these is the adaptive signal processing work in which available theory is used either to help train the network or at least to help define what experimental data are most important to acquire and feed into the network. This is a very powerful tool which we will be able to use increasingly as we define the windows for it. Next I want to re-emphasize the fact that, as Don said, our ability to describe the scattering from a flaw is growing significantly. We're even beginning to develop a meaningful capability of doing the inverse problem. More uses for this capability (beyond the subject of standards that both Don and George Birnbaum talked about) should be sought.

Finally I want to focus attention on the most serious problem we now face. As I have mentioned before, this is concerned with the reliability of flaw detection. If we plot the probability of detection with any NDE technique against a flaw size parameter, we always find a result that shows a zero probability at zero size slowly transitioning to almost 100% at some much larger size. The closer we can come to a step function which occurs at a selected size on the flaw size axis, the better off we will be and the more efficiently we can use our NDE methods. To what extent can our growing quantitative capability impact this particular problem?

As the number of practical inferences which can be drawn from our growing knowledge continues to increase, it becomes more and more important to start focusing relatively more attention, as several people have been saying and as Don has said, at defining what at Asilomar I called the specific window to use these possibilities. These are the real current needs with definable objectives and payoffs which can make use of the new technologies. These windows can stimulate not only a valid specific product, but they can provide the initial signposts to guide reduction to practice efforts into broad areas of use for the new knowledge. They generate enthusiasm and they also provide direction to the continuing research base. The work of the theorists can also be greatly helped if they know what they are looking for, what questions they are expected to answer. I challenge all of you, both scientists and technologists, to increase your efforts to define the specific ways our emerging knowledge can be put to use. And I thank you for what I think has been a very stimulating and effective symposium.

D. O. Thompson: Thank you, Harris. I would simply like to add that all of us in the program have benefited significantly from the guidance that our monitors, yourself, and your staff have provided. We consider it a privilege to be provided with an opportunity to utilize science in the solution of problems.

Again, I would like to take this opportunity to express our appreciation to the people at Cornell who have made so many efforts to cooperate with us. These include, of course, Professor Herb Johnson and his assistants, Mr. Noel Desch, and Mrs. Sharon Wellman. I'd like to thank all of our colleagues who contributed to the presentation of the program. Professor Jim Krumhansl, who has been a member of our program from the start, made the initial suggestion that we hold the meeting at Cornell this year. We are certainly grateful for the invitation, Jim. Finally, I'd like to express our thanks to our hostesses, Diane Harris from the Science Center, who has effectively coordinated most of the meeting from the Science Center end, and Ms. Kris Molt from Cornell who has operated as her counterpart here. We certainly do appreciate all these efforts and I hope that you all have a good meeting.