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ACOUSTO-OPTIC SIGNATURE ANALYSIS FOR INSPECTION OF THE ORBITER THERMAL PROTECTION TILE BONDS

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INTRODUCTION

The goal of this research is to develop a viable, noncontacting NDE technique for the inspection of orbiter thermal protection system (TPS) tile bonds. Phase II, discussed here, concentrated on developing an empirical understanding of the bonded and unbonded vibration signatures of acreage tiles. Controlled experiments in the laboratory have provided useful information on the dynamic response of TPS tiles. It has been shown that several signatures are common to all the "pedigree" tiles. This degree of consistency in the tile-SIP (strain isolation pad) dynamic response proves that an unbond can be detected for a known tile and establishes the basis for extending the analysis capability to arbitrary tiles for which there are no historical data.

The field tests of the noncontacting laser acoustic sensor system, conducted at Kennedy Space Center (KSC), investigated the vibrational environment of the Orbiter Processing Facility (OPF) and its effect on the measurement and analysis techniques being developed. The data collected showed that for orbiter locations, such as the body flap and elevon, the data analysis scheme, and/or the sensor, will require modification to accommodate the ambient motion. Several methods have been identified for accomplishing this, and a solution is seen as readily achievable. It was established that the tile response was similar to that observed in the laboratory [1]. Of most importance, however, is that the field environment will not affect the physics of the dynamic response that is related to bond condition. All of this information is fundamental to any future design and development of a prototype system.

DEVELOPMENT OF ACOUSTO-OPTIC TECHNIQUES

Phase II has seen important progress in the area of sensor development. There is now a much better understanding of the sensor's capabilities and limitations. The sensor response has been modeled and verified with experiments using a piezo pusher. In addition, a long focal length lens has been incorporated that allows data collection at up to 10 m away [2].

The laser cavity response to light scattered from vibrating surfaces has been successfully modeled. The model has been used to explain several characteristics of the signal that arise when the vibration amplitude exceeds half the light wavelength [2]. If the model's criteria are violated, then nonlinear effects are predicted. These nonlinear effects have been observed. Frequency doubling occurs when the vibration displacement approaches the magnitude of a wavelength of laser light. Signal attenuation and frequency doubling are observed when the "at rest" distance to the sample violates nonlinearity. This understanding will

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result in improved performance with the existing hardware and possibly development of an improved servo scheme that will allow the sensor to accommodate large amplitude vibrations, such as the ambient vibrations encountered in the OPF. The model is presently being used to study improved methods for extracting the vibration signal.

TILE RESPONSE STUDIES

The goal of the tile response studies was to develop an empirical understanding of the bonded and unbonded vibration signatures of acreage tiles covering the underside of the orbiter. Pedigree tiles were used in controlled unbonding experiments to reduce effects due to differences in tile geometry. A limited number of unbond geometries were simulated using a vacuum mounting fixture specially designed for this project. The experimental work clearly shows that bond condition affects tile response in consistent and quantifiable ways.

The vacuum mounting fixture will first be described to facilitate an understanding of experimental methods. Experimental results will then be presented.

Vacuum Chuck

A vacuum chuck for easy simulation of unbonds was developed. (During Phase I, unbonds were simulated by first bonding the tile to an aluminum plate and then slicing through regions of the SIP with a razor blade to mimic unbonds. An easier and more repeatable method of simulating unbonds was needed.) The vacuum chuck is an aluminum plate with a nearly square array of vacuum holes, slightly smaller than the 5 x 5 in. SIP (Figure 1). When a SIP is mounted backwards on a tile, such that the RTV side faces out, the tile can be securely held by placing the RTV-sealed SIP against the face of the chuck and drawing a vacuum. Unbonds are simulated by taping over regions of vacuum holes. Tests were conducted to study the repeatability of tile response with bonds simulated using the vacuum chuck. Tiles were mounted on the vacuum chuck at times separated by a few weeks with little effect on the dynamic response.

Tile Bond Analysis

The central thesis of this work is that bond condition can be determined by studying the vibrational response of a tile excited by acoustical energy. Investigations have centered on identifying response characteristics that reliably predict unbonds. A number of characteristics have emerged as promising candidates for this purpose and will be discussed in this section. The primary focus of the discussions will be on results obtained with the pedigree tiles, using the vacuum chuck to simulate unbonds. Before considering response characteristics of unbonded tiles, a brief description of tile vibrational modes is in order.

The vibrational modes of a TPS tile can be of either the rigid body type or the flexural type. In rigid body modes, vibration results from rocking, piston, or twisting actions of the rigid tile against the spring action of the SIP. Twisting motions will not be considered here because the displacement sensors used for this work detect only motion normal to the tile surface. In the flexural modes the tile bends as it vibrates; tile

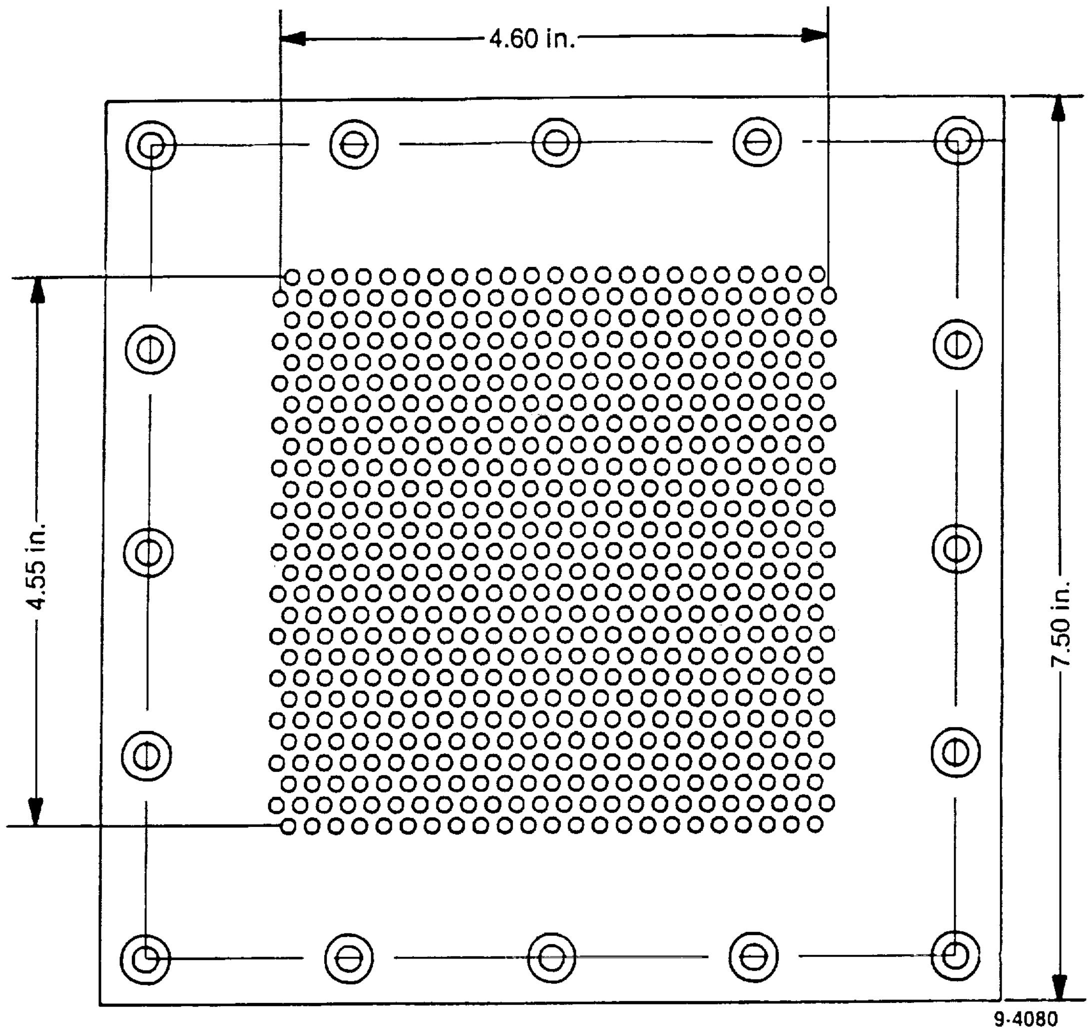


Fig. 1. Vacuum chuck.

stiffness provides most of the spring action. For TPS tiles examined to date, the frequencies of the two types of vibrational modes fortuitously separate into distinct nonoverlapping ranges; the rigid body modes appear below 1400 Hz, while the flexural modes appear above 1600 Hz. This separation aids in the interpretation of some of the phenomena observed in tile vibrational responses.

A number of characteristics have emerged as promising candidates for unbond indicators. They are listed here and explained in the text which follows.

1. Downward frequency shift of rigid body modes.
2. Amplitude of the vibrational response.
3. Elongation of initial oscillations in transient tile response.
4. Asymmetrical response characteristics in unbonded tiles.

Downward Frequency Shift of Rigid Body Modes

In order to quantify the frequency shifts as unbonding progresses, a measure of the center frequency for each unbond condition is needed. Four measures of the center frequency of the rigid body modes were developed and evaluated. All operate on spectra over the rigid body frequency range of 0 to 1400 Hz. Spectra are calculated using fast Fourier transform (FFT) without windowing. The magnitude of the FFT terms is used in two of the center frequency calculation methods; magnitude squared is used in the remaining two.

The methods were evaluated by applying them to data collected during unbonding experiments with three pedigree tiles--9073, 9074, and 9075. The vacuum chuck was used to simulate unbonds. Data were collected from the three tiles under four bond conditions: fully bonded, 25% unbonded, 50% unbonded, and 100% unbonded. The 25% unbond was a 2-1/2-in. square region in the upper right corner of the 5-in. square SIP. The entire top half of the SIP was unbonded in the 50% unbond tests. The 100% unbond data were collected while the tile was lying face-up on the optical table; this is also referred to as a back shop measurement. Filler bar was present for all measurements, except, of course, for the 100% unbond case. Data were collected at three points on each tile, as illustrated in Figure 2: top center, center, and lower center. Results from the three tiles, for the top center point, are summarized in Figure 3.

Center frequency (as defined above) shows promise of being a reliable unbond indicator when the sample point is near an unbond. To use center frequency for unbond determination, the "good" center frequency must be known beforehand. It may be possible to determine this from knowledge of tile geometry. However, it may not be possible if center frequency is very sensitive to minor variations in geometry or to random variations introduced during mounting. If the latter is true, center frequency may still be used for bond analysis, but it would require an empirical determination of the "good" value after mounting. The technique would not then be useful for inspecting initial tile installations but would be used for postflight examinations. Results obtained from the pedigree tiles suggest that "good" center frequencies may be accurately predicted from nominal geometries. More study of center frequency and the factors that affect it is required.

Amplitude of the Vibrational Response

Larger vibrational amplitudes have been found to correlate with unbonds. Figure 4 shows time series data collected from tile 9074. A relationship between amplitude and the presence of an unbond is evident. However, amplitude also depends on the relative locations of the unbond and sample point. The peak-to-peak amplitude is largest when the unbond is across the bottom. When this is the case, the sample point is over the unbond, and the peak-to-peak amplitude is double the amplitude of the fully bonded tile. When the unbond is along the right side, the sample point is also over the unbond, but the increase in amplitude is only 36%. When the sample point is not over the unbond, the increase is less evident or absent.

The amplitude data discussed here were not collected with the point sensor developed for this work. That sensor has some outstanding characteristics, but measuring absolute amplitude is not one of them. The problem stems from the fact that measurements are proportional to the brightness of reflected light, as well as displacement. The reflectivity of

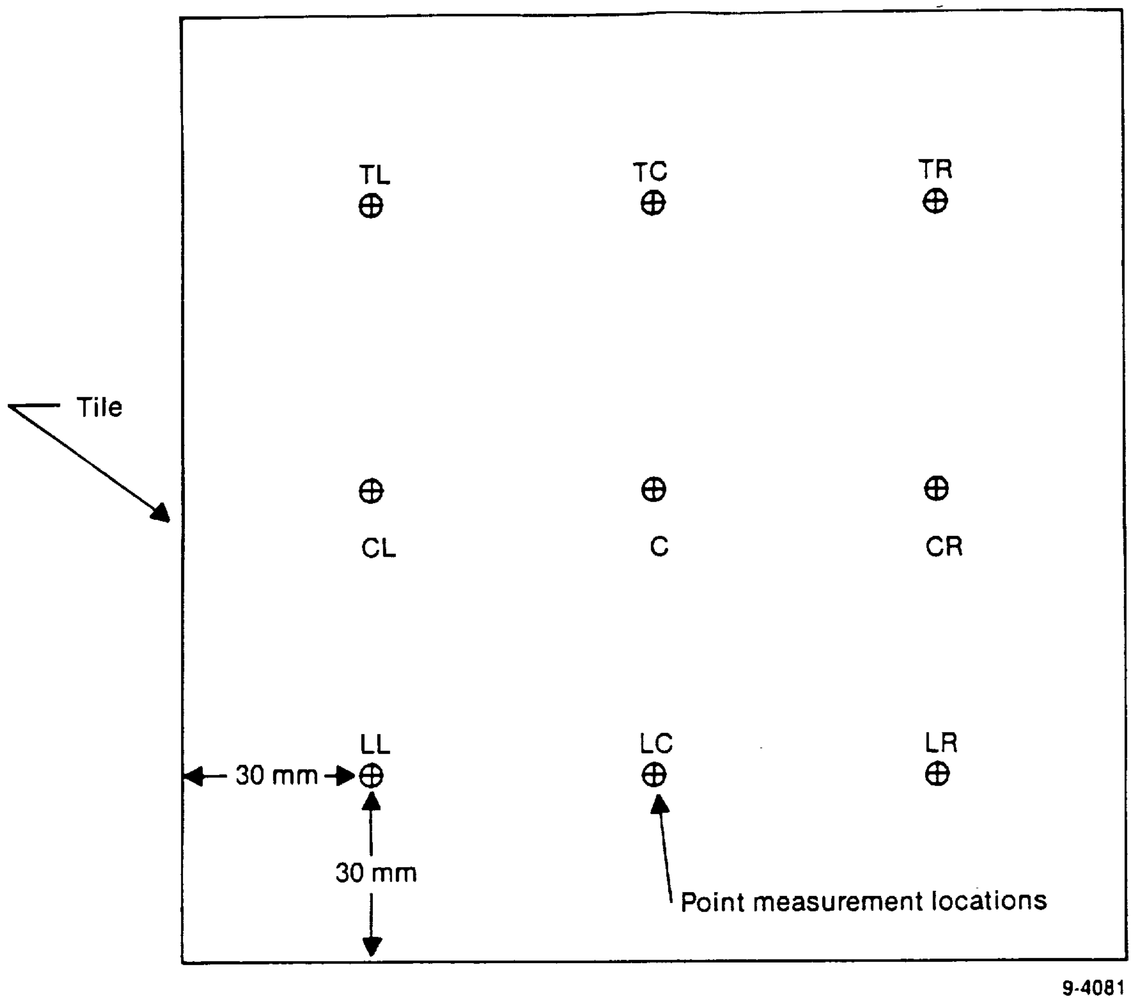


Fig. 2. Vibration measurement points.

tiles varies from point to point, thereby precluding comparison of amplitude data from two different points on a tile. Amplitude data were collected with a laser vibrometer that requires attaching a mirror to the tile. This system is suitable only for laboratory use because of the mirror requirement. The existing sensor could be used on the orbiter if it were possible to calibrate it at each sample point. A fairly simple method of calibration using a dither signal has been proposed. If amplitude is determined to be a necessary measurement for unbond detection, it is felt that an appropriate sensor could be developed with existing technology.

Elongation of Initial Oscillations in Transient Tile Response

The first few milliseconds of tile vibration following excitation exhibit a characteristic that predicts unbonds in the pedigree tiles. This characteristic is the duration of the first few oscillations in the time series data. Figure 5 shows the first 3 ms of time series data for three bond conditions. As unbonding increases, an elongation of the oscillations occurs and the time between zero crossings increases. This phenomenon may be the time domain equivalent of the downward frequency

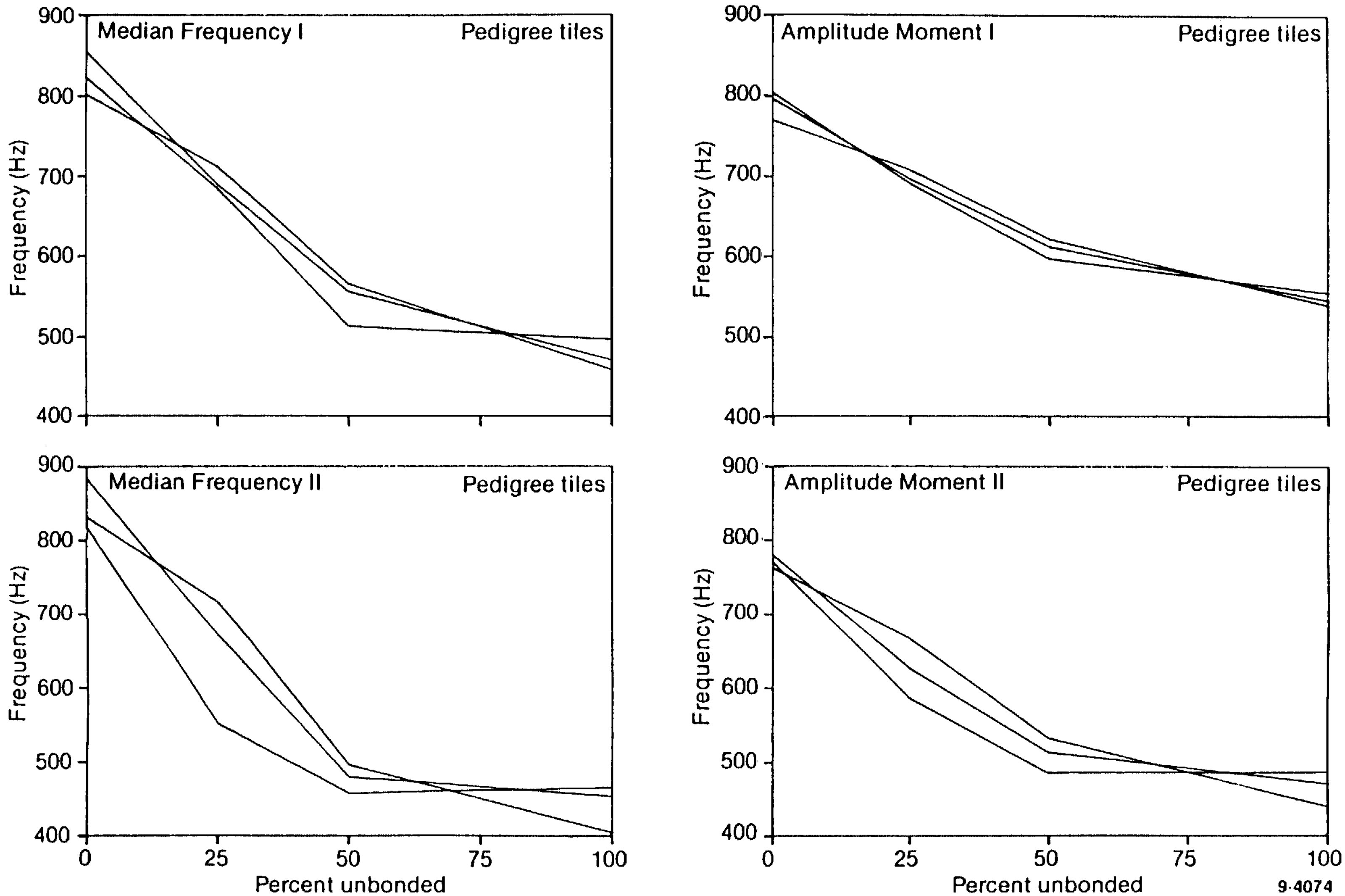


Fig. 3. Calculated center frequency as a function of percent of unbond for the top center point of the three pedigree tiles. The results of four different methods are shown.

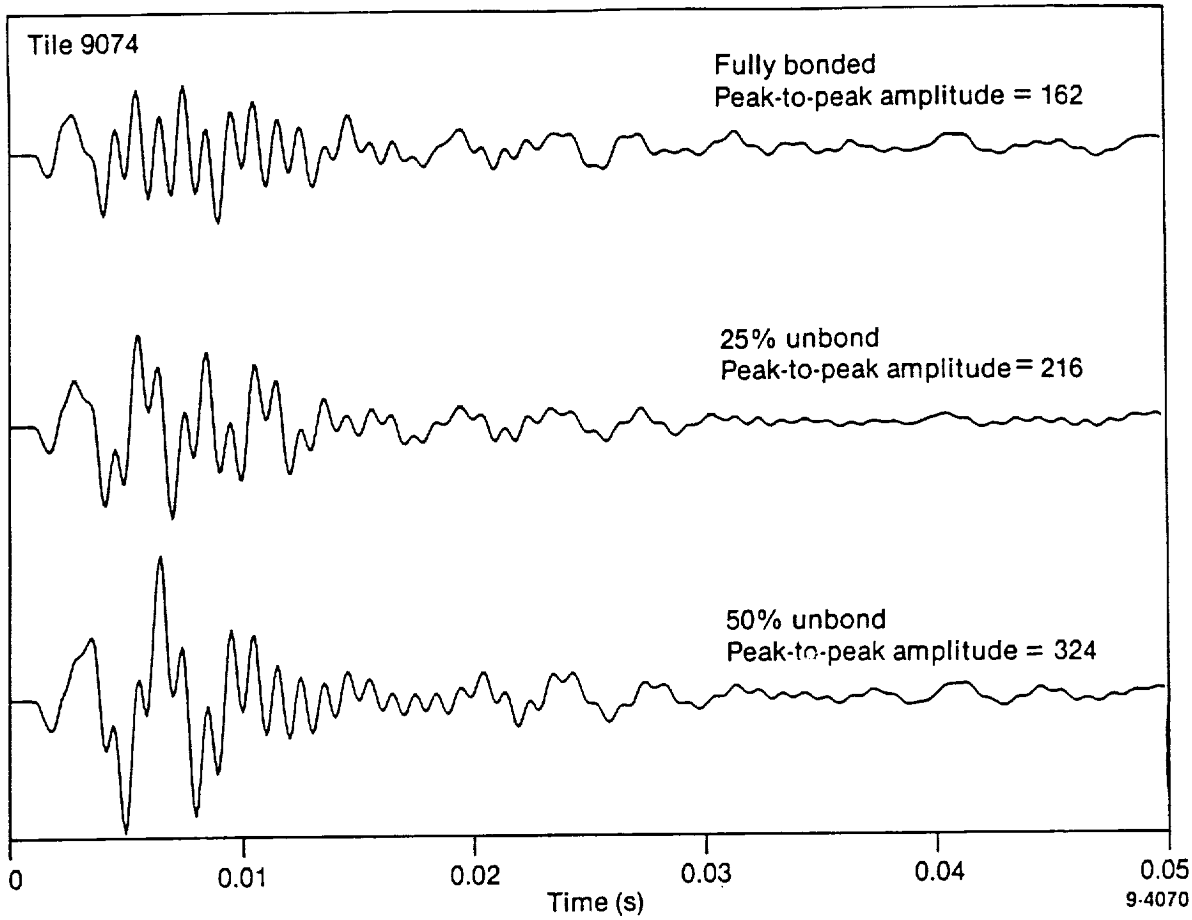


Fig. 4. Effects of unbonds on amplitude.

shifts observed in the rigid body modes. If so, there may be little to gain in studying both phenomena as the bond condition information contained in one may be duplicated in the other. On the other hand, the two may not be that closely related. The time domain phenomenon may provide information about resonance modes not observable in estimated spectra. Spectra estimated using FFT techniques necessarily represent time averages of the frequency content of a signal. The frequency content of a transient process, such as tile dynamic response, changes with time (the process is nonstationary). A time average may not adequately represent the frequency content at a particular time, especially if dominant resonance modes at that time are rapidly decaying. Hence, there is reason to continue consideration of this time domain unbond indicator.

Unbond effects on initial oscillations are affected by the relative locations of the sample point and unbond. Elongation of initial oscillations diminishes as the distance between sample point and unbond increases. Evidence suggests that the relative positions of speaker and unbond may also be significant. This is very similar to the behavior of unbond indicators already discussed. The data from unbonded tiles plotted in Figure 5 were collected at points over the unbonds.

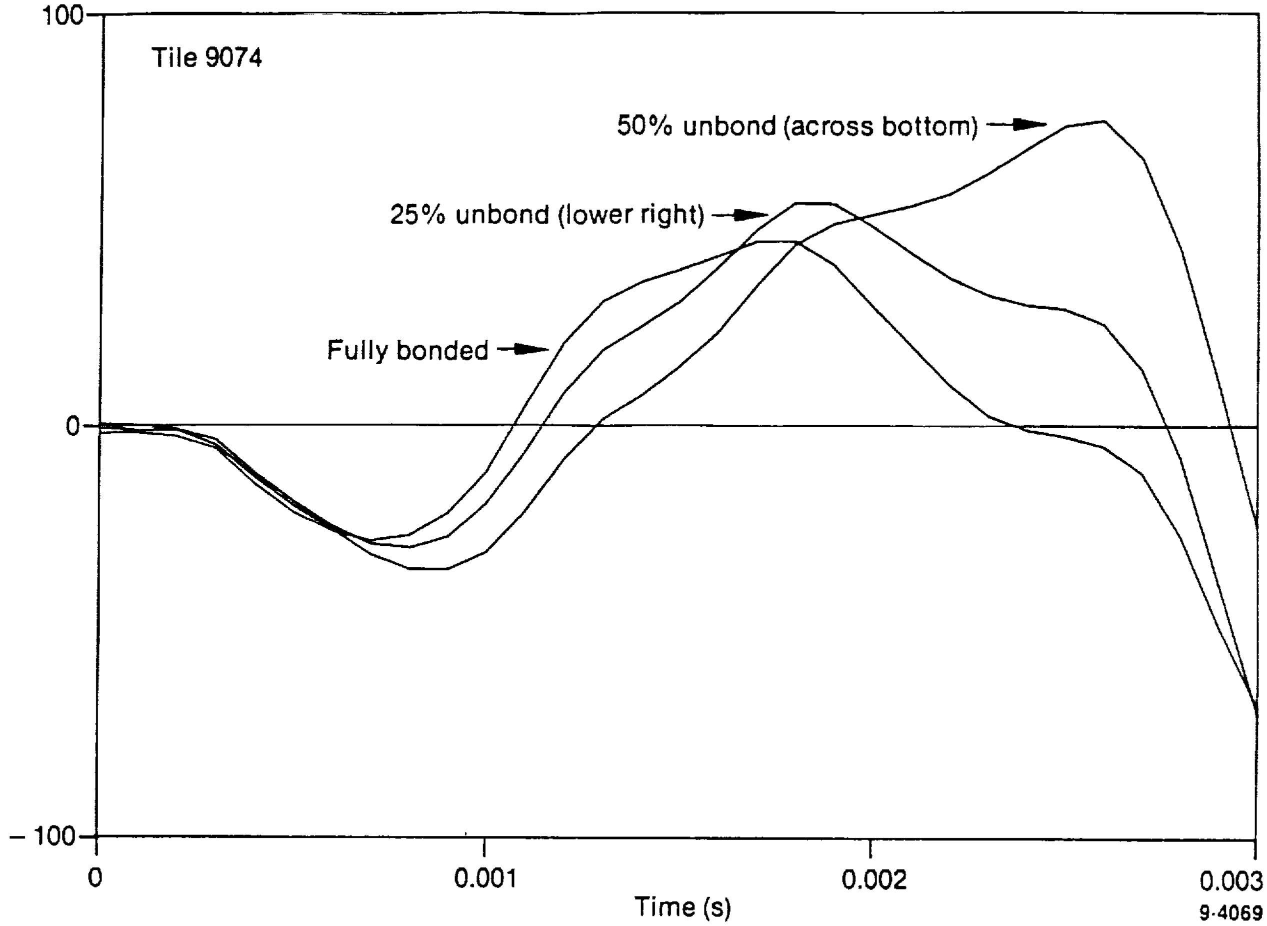


Fig. 5. Effects of the unbond on the initial oscillation.

Asymmetrical Response Characteristics in Unbonded Tiles

The tile response characteristics discussed above exhibit a dependence on the relative locations of the sample point, unbond, and speaker (excitation). This behavior suggests that an asymmetrical response may be useful for identifying unbonds. Asymmetrical behavior of an unbonded tile is illustrated in Figure 6, which shows the response of a bonded tile at two measurement point locations, top left and top right. The speaker position is the same for all plots. It is apparent that the differences in top right and top left spectra are greater when an unbond is present; the spectrum at a given point is apparently more sensitive to changes in speaker location when an unbond is present.

This unbond indicator is particularly attractive since it does not require prior assumptions about "good" tile behavior. It is based on the following two premises:

1. An asymmetrical bond results in asymmetrical tile dynamic response characteristics.

2. Asymmetrical behavior normally observed in bonded tiles is much smaller than asymmetrical behavior due to significant unbonds.

More work is required to verify these two assumptions, as well as devise a method of quantifying spectral asymmetry. Finally, it is clear that this unbond indicator would not detect symmetrical unbonds.

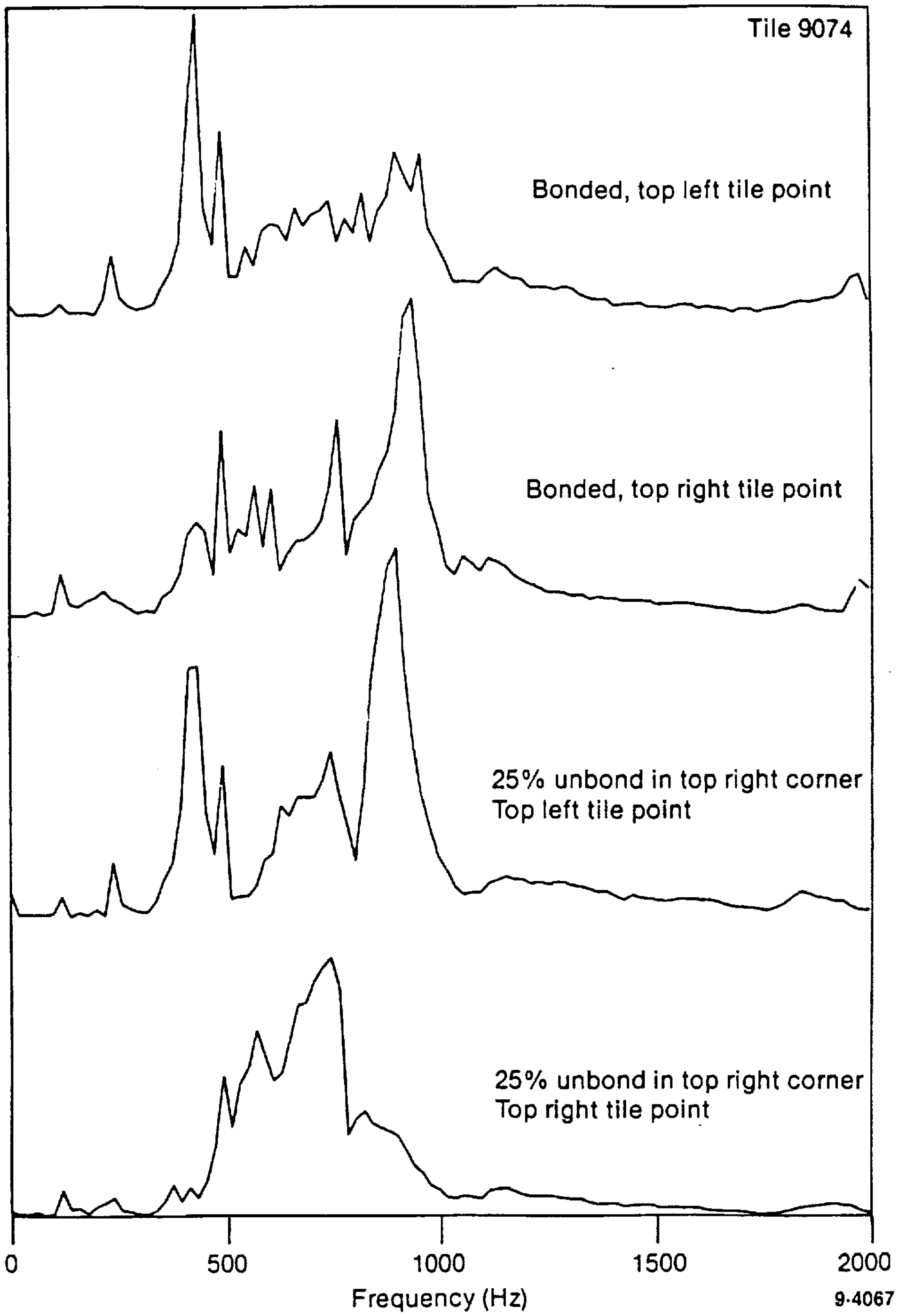


Fig. 6. Effect of sample point location.

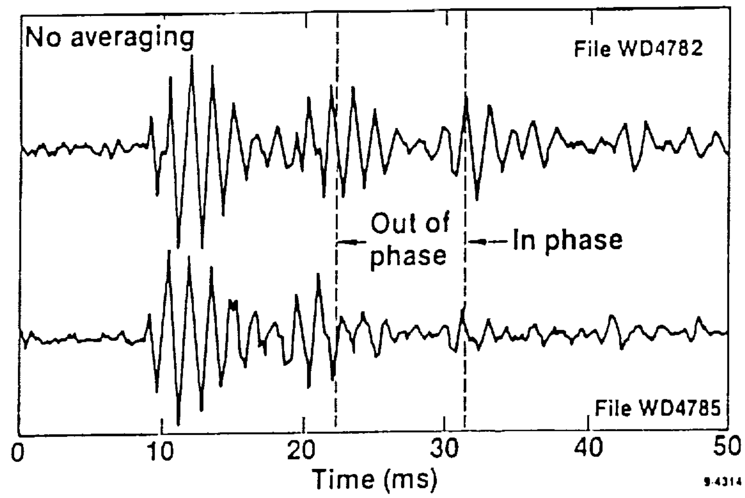
FIELD TESTS

The field tests conducted in July of 1988 verified that tile resonances were detectable in the Orbiter Processing Facility environment. The field tests established that the vibration isolation of the sensor system, the long focal length optics, and the excitation methods could function in a field environment. There was no difficulty in obtaining an adequate reflection from the normal tile surfaces, and the pneumatic tires on the cart carrying the laser provided sufficient vibration isolation for the system. However, the measurements, which were made on the Orbiter Columbia, also showed that the sensor response was complicated by ambient motion of the orbiter. While small (~10 μm at 20 Hz), these motions were detected by the sensor and frequently masked the induced excitation. Figure 7 shows TPS data collected near the external tank doors. The data in the two unaveraged data sets in Figure 7a changed phase during our collection period of 50 ms due to the ambient motion. For the 25 averaged data sets shown in Figure 7b, the collection period could be reduced from 50 to 8 ms due to signal cancellation caused by the ambient motion. The motion taking place on the orbiter has reduced the amount of information that the current collection technique can obtain.

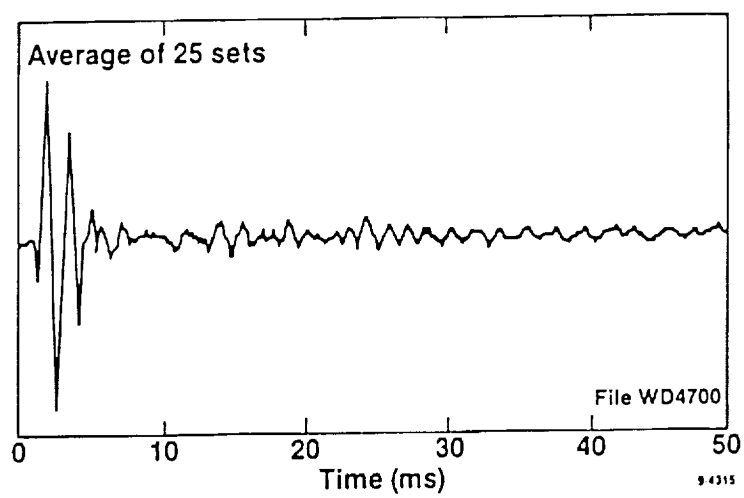
Due to the large ambient motion, a fieldable system will require modification of either the sensor or the way the resonance information is extracted with the existing sensor. Details of these options are given below; an evaluation of these approaches is being conducted as part of ongoing work.

There are at least two approaches to overcoming the difficulty caused by the ambient motion of the orbiter. The first is to modify the data analysis so that the sensor nonlinearities do not obscure the desired information. This is possible because the large amplitude ambient vibrations do not change the physics of the bond's effect on the tile's dynamic response; a different measurement technique may be required, but the effect is still there. Some possible modifications are to confine the analysis to the first 5 ms after excitation or to measure peak amplitudes of resonance vibrations induced by a CW tone. The latter technique was actually used during the field test at selected resonances. Figure 8 presents data collected on one of the control surfaces. Here a CW tone was used to excite a tile vibration resonance. The data show that during a "turnaround" point the CW tone can be captured and used for data analysis. The second approach would be to continue sensor development to obtain a sensor that is linear over the required range of vibrations. The approach taken to date has been to use the existing sensor capability, unless and until it is necessary to expend additional resources to acquire a sensor capable of handling large ambient motion. These two approaches are currently being evaluated.

The most significant finding of the field tests is that the response of the tiles on the orbiter is similar to that observed in the laboratory. While it was not possible, or intended, to vary bond conditions on the tiles examined, it was possible to excite resonances and measure their existence with the acousto-optic sensor in a different fashion than the standard data collection method. Quantification of the ambient vibrations of the OPF environment was also significant as their impact can now be incorporated into any future design of analysis techniques and/or sensors.



a. Two unaveraged data sets.



b. Average of 25 data sets.

Fig. 7. KSC field data near external tank door.

EXTERNAL CAVITY

Now that the OPF vibrational environment has been characterized, it is necessary to choose a sensor to operate in this environment. An external cavity has been added to the existing sensor. The cavity consists of a mirror mounted on a piezo pusher and placed in the beam path to the tile. As excessive motion of the tile is sensed, the mirror is moved in an opposite direction to compensate for the motion. The two types of vibrations are separable by filtering since the large amplitude vibrations are generally of lower frequency than the signal of interest. The cavity can compensate for large low-frequency ambient vibrations of less than 100 Hz (Figure 9). The control signal for this cavity variation is derived from the displacement signal output from the laser

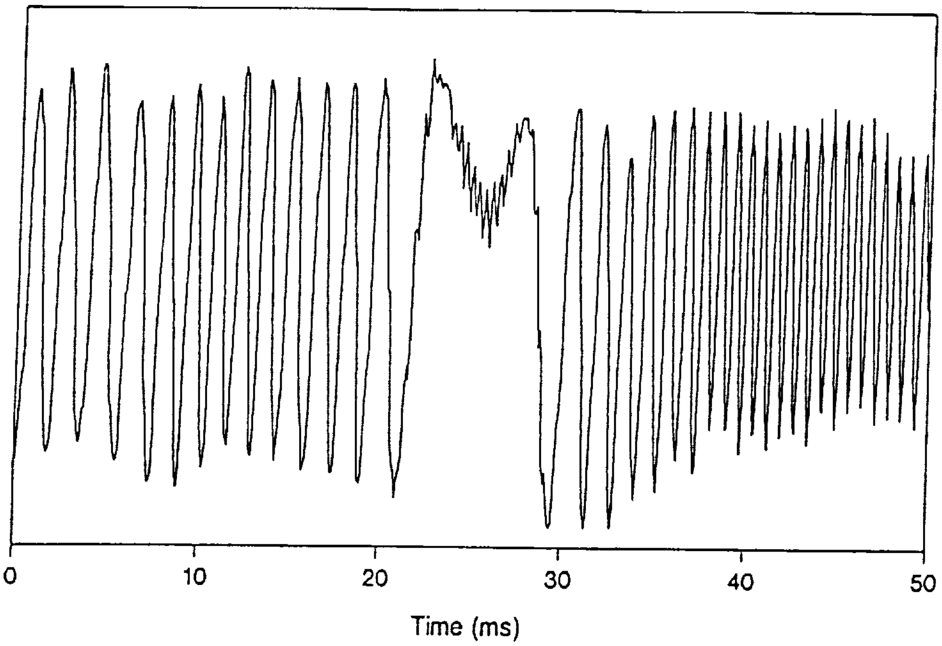


Fig. 8. KSC field data on elevon.

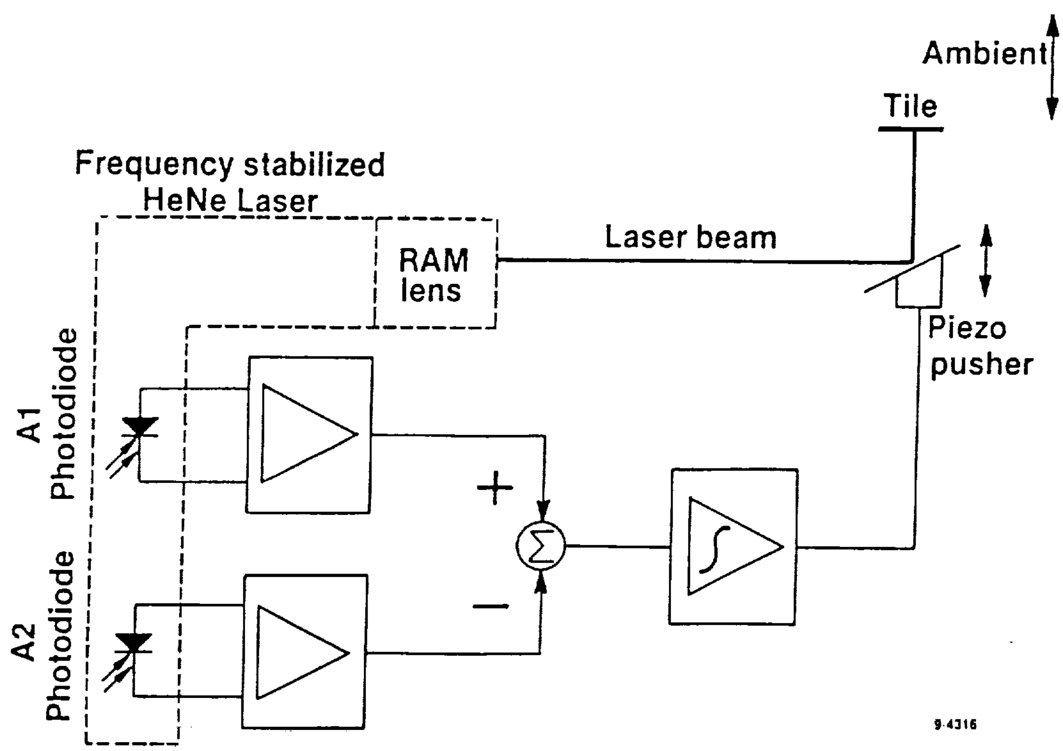


Fig. 9. External cavity block diagram.

sensor. The external cavity has been used to prevent phase inversion of the signal, proving in principle that the approach is capable of improving the fidelity of the signal.

CONCLUSIONS

The past year's work had two basic objectives. The first was to continue development of the sensing technology to the point where preliminary field measurements on the orbiter could be made. This goal was achieved, thanks in large part to the development of the long focal length optics. Valuable information obtained from the field experiments clearly identifies areas where future efforts should be applied.

The second goal was to advance the state of understanding of the physics of tile vibration and vibration measurement to the point where an informed decision could be made on whether or not this approach is viable for field detection of real flaws on the orbiter TPS. This goal was also achieved; concentrating on the pedigree tiles, a number of quantifiable unbond signatures were identified.

The following conclusions summarize the results of Phase II work on this project.

1. Vibration signatures associated with bond flaws are significant, repeatable, and consistent between similar tiles with similar bond flaws. A number of promising bond flaw signatures have been identified. These signatures are quantifiable and consistent among the pedigree tiles. Signatures include frequency and time domain features of the dynamic response, as well as symmetry observations.

2. The measurement techniques developed for this project can work in a field environment. An optical table is not required to make extremely sensitive displacement measurements; the sensor can operate in normal workplace "noise."

3. Modifications to the sensor or to analysis techniques are necessary to accommodate the large ambient motion present in some areas of the orbiter.

The field tests revealed that the ambient vibration of the orbiter is too large for the current sensing method and/or analysis techniques. The current sensor is very good at sensing vibrations with peak-to-peak amplitudes less than 0.5 μm. Motions greater than 13 μm were measured in some areas of the orbiter during the field tests.

ACKNOWLEDGMENT

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2. B. A. Barna, D. M. Tow, R. T. Allemeier, J. G. Rodriguez, and J. A. Johnson, "Laser Detection of Acoustic Displacement by Destabilizing a Frequency Stabilized Helium Neon Laser," Review in Progress in QNDE 8A, edited by D. O. Thompson and D. E. Chimenti (Plenum Press, New York, 1988) p. 543.

PC-BASED NDE SIGNAL ACQUISITION & ANALYSIS

Tony Mucciardi

Infometrics, Inc.

2nd. Conference on Nondestructive Evaluation for Aerospace Requirements
August 22-24, 1989 Huntsville, AL

ANALOG UT INSPECTION

CRITERIA

- Amplitude Exceeding a Threshold in a Time Gate
- Echo Dynamic Pattern of Indications

PROBLEMS

- Threshold Alarm Alerts Inspector of Indication, but not its Identity
- Inspector's Expertise is Often Not Adequate for Proper Decision
- No Way for Independent Third Party Evaluation without Repeating Entire Inspection & Relying, once more, on Another Inspector's Expertise

DIGITAL UT INSPECTION

- If the Transducer Signal is Digitized & Recorded During the Initial Inspection, Further Analyses can be made -- both by Individuals & by Software Algorithms -- without Repeating the Inspection

- This Archival Capability also Permits the Waveform to be Compared -- Along with its Features -- to Data Recorded in Other Inspections

- Digital Storage of UT RF Waveforms also permits Signal-to-Noise Enhancement Algorithms to be applied to Eliminate, or at least greatly reduce -- Undesirable Signal Contaminants such as Grain Noise, etc.

WHY PCs ?

- FIELD WORTHY - Designed to operate in Office / Work Area w/out Need for Specially Controlled A/C Environment

- SIZE - Portable Versions are quite Rugged & Easy to Transport

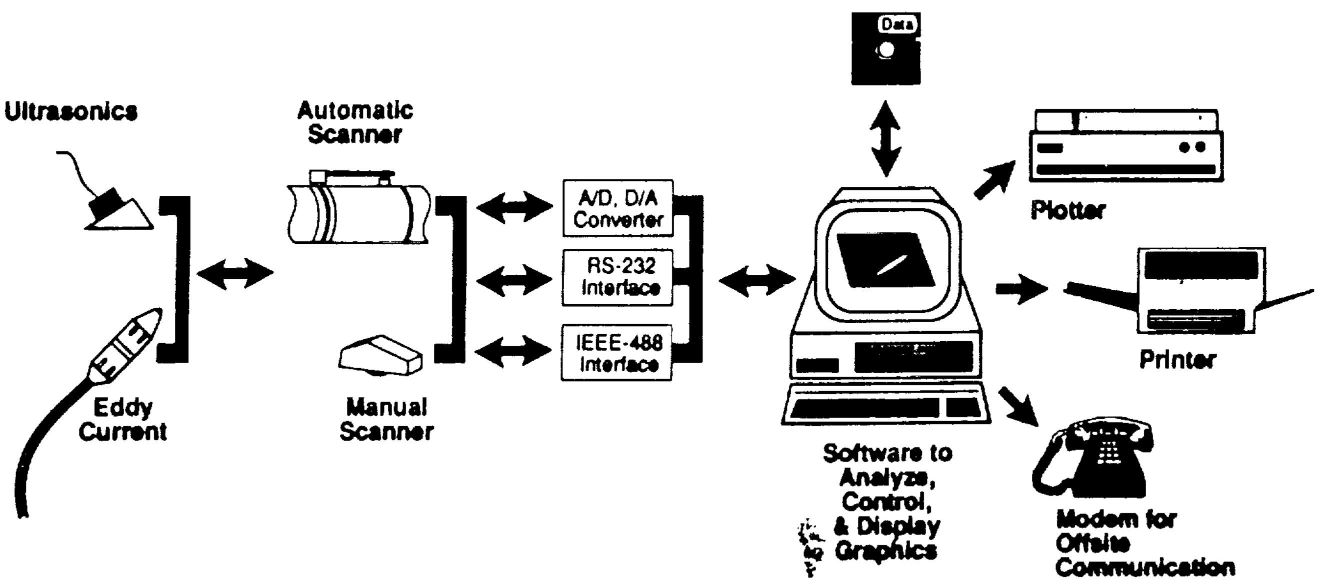
- ARCHITECTURE - PC Bus Architecture allows the Integration & Intelligent Control of User-Supplied Boards; mass storage is very cheap

- PRICE - Very Inexpensize

- POWER - With 386-class Machines, PCs have Main Frame Speeds

- PARTS - Readily Available World-Wide

PC-Based Workstation for NDE



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COMPONENTS OF UT SIGNAL PROCESSING

TRANSDUCER CHARACTERIZATION

- Transducer Evaluation -- time/frequency
- Sound Beam Profiler -- immersion/contact
- Auto Specs + User Specs

DATA ACQUISITION & PROCESSING

- Data Acquisition (multi-channel)
- Clustering
- 3-D Graphics (CAD-like)
- Signal Processing/Filtering (S/N enhance.)
- Lotus 1-2-3 Spreadsheet i'face
- dBase III i'face
- Communications (modem)
- Word Processing/Reporting
- User-Supplied S'ware

FLAW CLASSIFICATION

- Training (auto. Pattern Recognition)
- Analysis

IMAGING

- C- and B-Scans
- 3-D C-scans
- Off-line C-scan Reconstruction
- Image Processing functions

COMPONENTS OF UT SIGNAL PROCESSING

EDDY CURRENT

- Phase Plane analysis
- Multi-Channel
- Multi-Frequency
- Auto. Mixing Algorithm
- Store on Hard Disk for further analyses

SIGNAL QUALIFICATION

- Flaw Detector raised to higher level
- Multiple Gates (inc. overlap)
- Threshold "sense"
- "Analysis" Gate (real-time flaw classif.)
- Alarm menu
- Alarm-disposition menu
- Real-Time S/N Enhancement display

TRANSDUCER EVALUATION TEST

TESTPRO TRANSDUCER EVALUATION TEST
ULTRASONIC TRANSDUCER REPORT
Report_Date: Thu Mar 23 10:59:59 1989

USER PARAMETERS

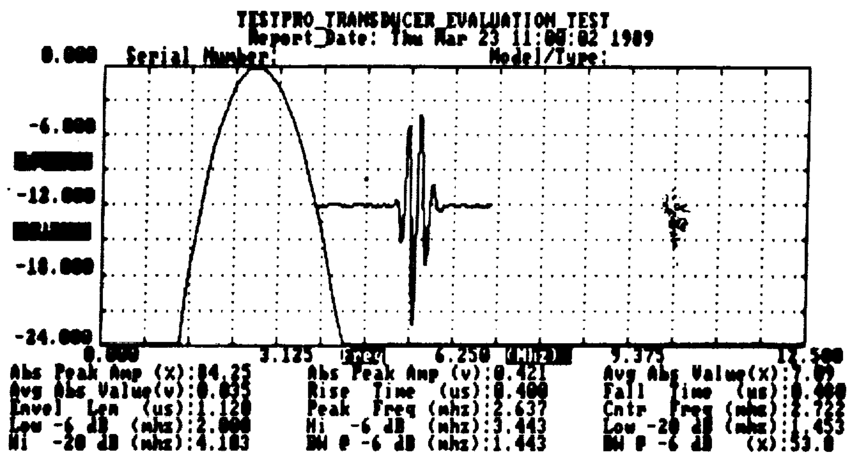
TRANSDUCER ENTRIES

Serial Number:	144517	**Model/Type:**	Gamma
Manufacturer:	KB Aerotech	**Imersion/Contact:**	Contact
Diameter (in):	0.500	**Focal Length (in):**	n/a
Cntr Freq(Mhz):	2.5	**Date Purchased:**	2-Feb-86

PULSER RECEIVER ENTRIES

Manufacturer:	Infometrics	**Gain:**	10dB
Model/Type:	PCPR-100	**Attenuation:**	40dB
Serial Number:		**Energy:**	175 Volts
Last Calibrate:	May-88	**High Pass Filter:**	50MHz

USER ENTRIES		**OTHER DATA**	
Tester:	Mucciardi	**Cal Block Type:**	Aluminum
Date of Test:	7-Jul-88	**Cable Length:**	1 Meter
Series Number:		**Shoe Type:**	Wedge
Hours of Use:		**Shoe Material:**	Lucite



SYSTEM PARAMETERS

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Start Freq (MHz):0.000	Hor Res(mhz/div):0.7813	Vert Res(db/div):3.000
Gate Start (us):20.280	Gate Length (us):5.120	Gate Length(pts):128
Sampl Rate (MHz):25.000	Waves Avged(num):1	Trigger(Int/Ext):Int
FFT Length (pts):256	DB Range (dB):24.0	Plot in DB (y/n):Yes
Pulser Volts (V):175	Damping (Ohm):634	PW Freq (MHz):2.240
Numbr Cycles ():1	Pulser Phase ():-Unipolr	Fixed Atten (dB):40
Attenuation (dB):30	LPass Filt (MHz):9.0	

FEATURES

Abs Peak Amp (%):84.25	Abs Peak Amp (v):0.421	Avg Abs Value(%):7.09
Avg Abs Value(v):0.035	Rise Time (us):0.400	Fall Time (us):0.480
Peak Freq (mhz):2.637	Cntr Freq (mhz):2.722	Low -6 dB (mhz):2.000
Hi -6 dB (mhz):3.443	Low -20 dB (mhz):1.453	Hi -20 dB (mhz):4.103
BW @ -6 dB (mhz):1.443	BW @ -6 dB (%):53.0	BW @ -20 dB(mhz):2.650
BW @ -20 dB (%):97.4		

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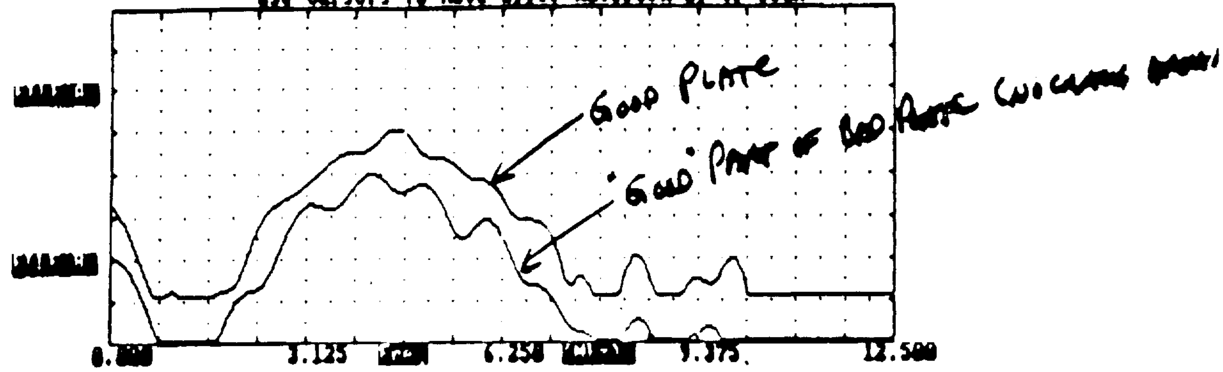
SPECTRUM COMPARISON

Use Cursors To Move Upper Waveform Up Or Down



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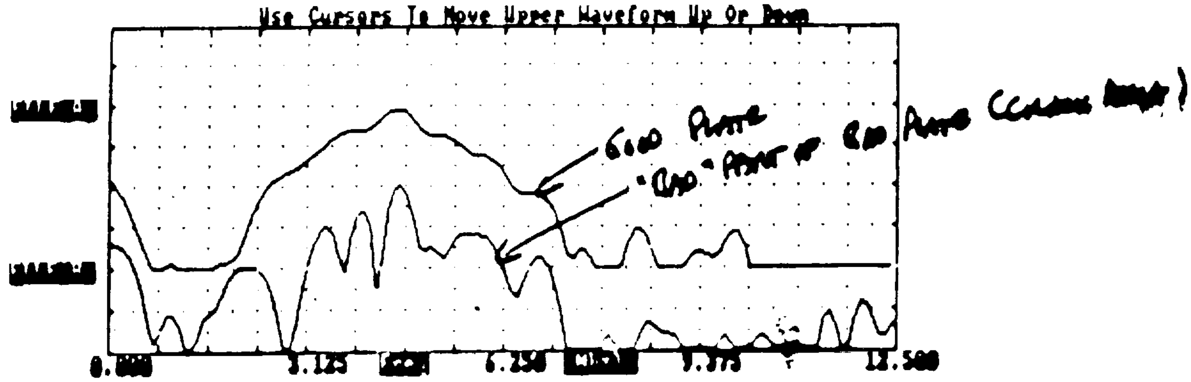
SPECTRUM COMPARISON

Use Cursors To Move Upper Waveform Up Or Down



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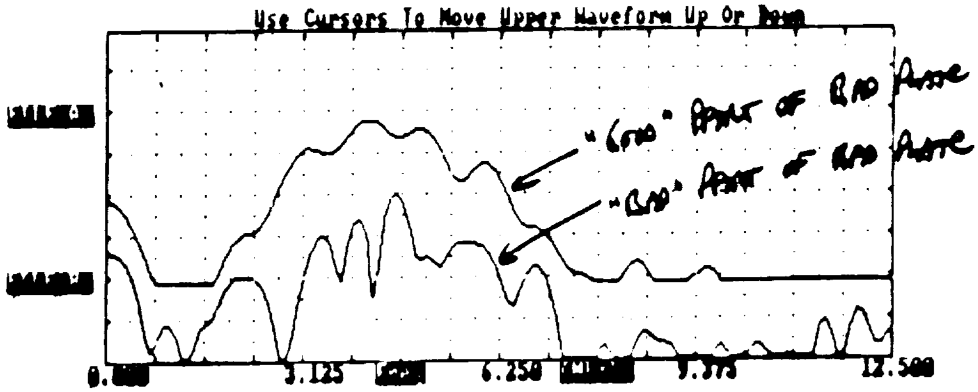
SPECTRUM COMPARISON

Use Cursors To Move Upper Waveform Up Or Down



Upper Waveform = Spectrum from record 1 of file C:\TESTPRO\USPOLY01.PD
Lower Waveform = Spectrum from record 2 of file C:\TESTPRO\USPOLY01.PD
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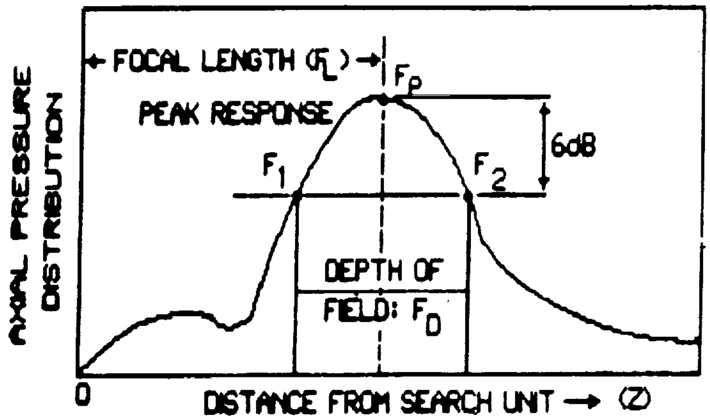
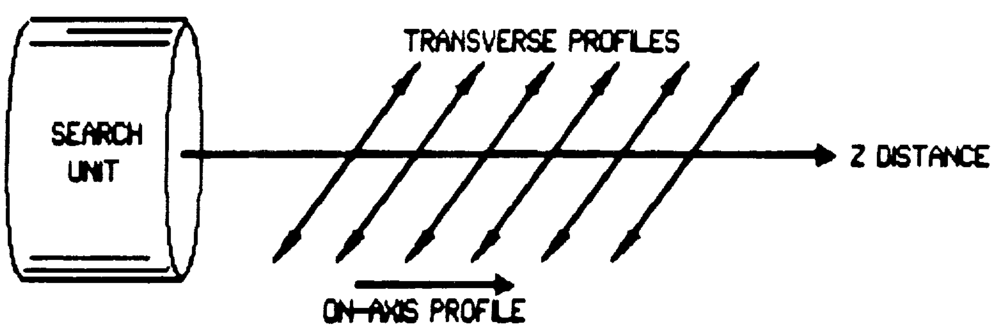


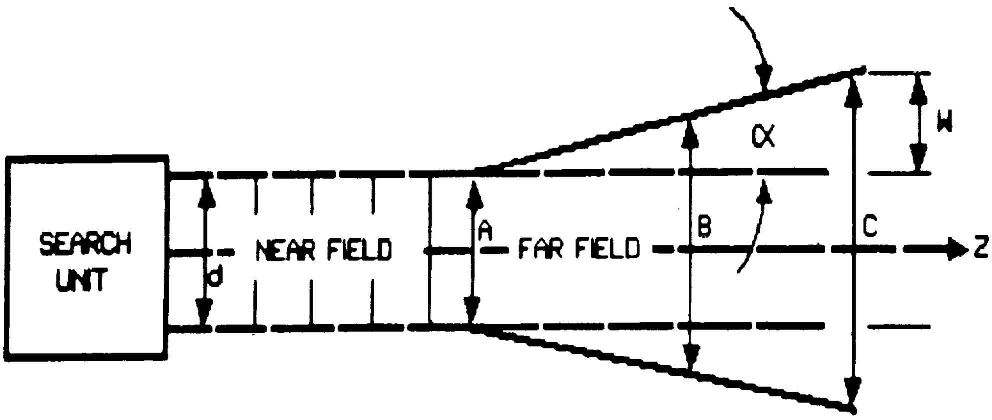
On-Axis Profile Parameters from Focused Search Unit

Fig. 1



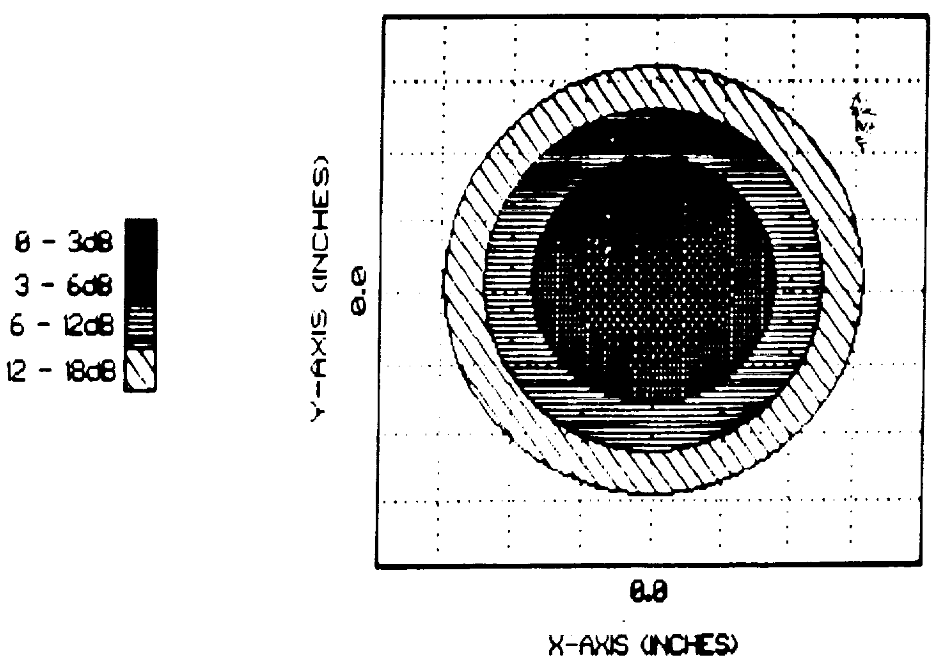
Sound Field Patterns: Transverse Profile

Fig. 2



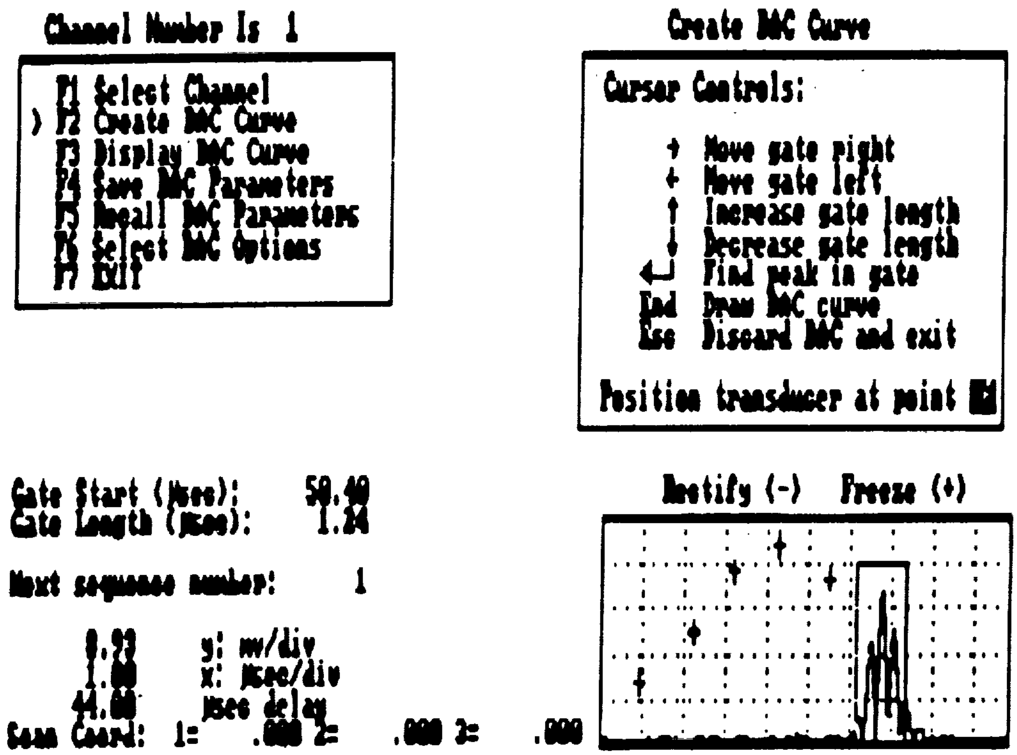
Sound Field Patterns: Beam Spread

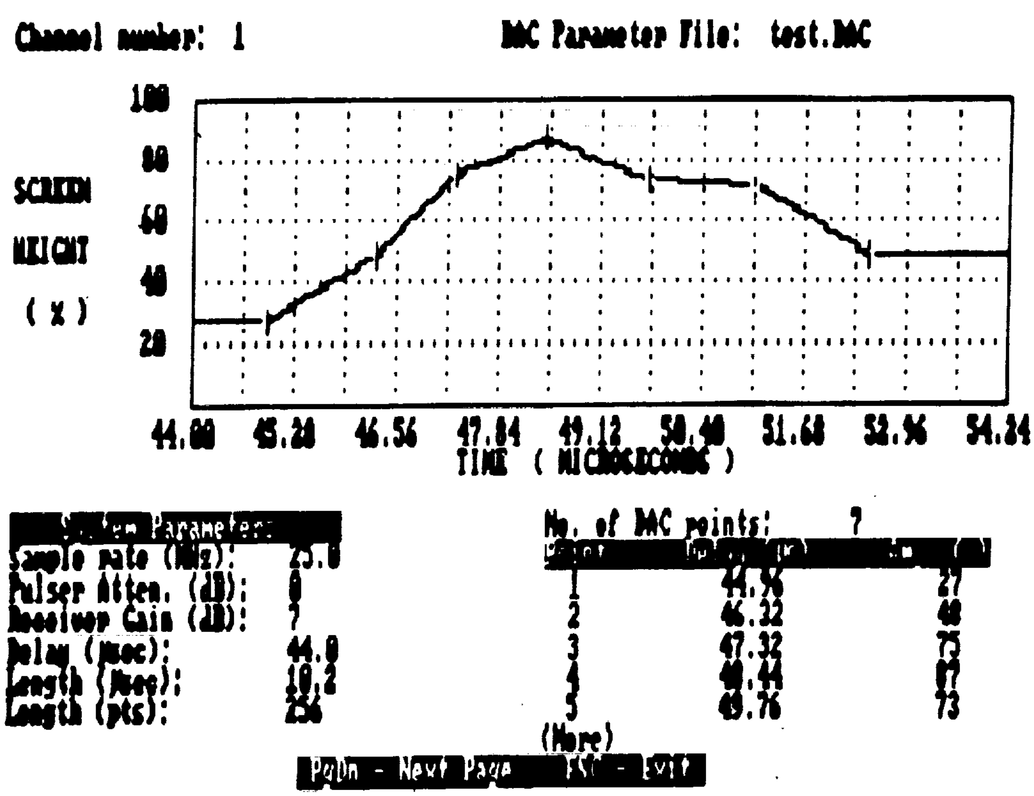
Fig. 3



Sound Beam Profile

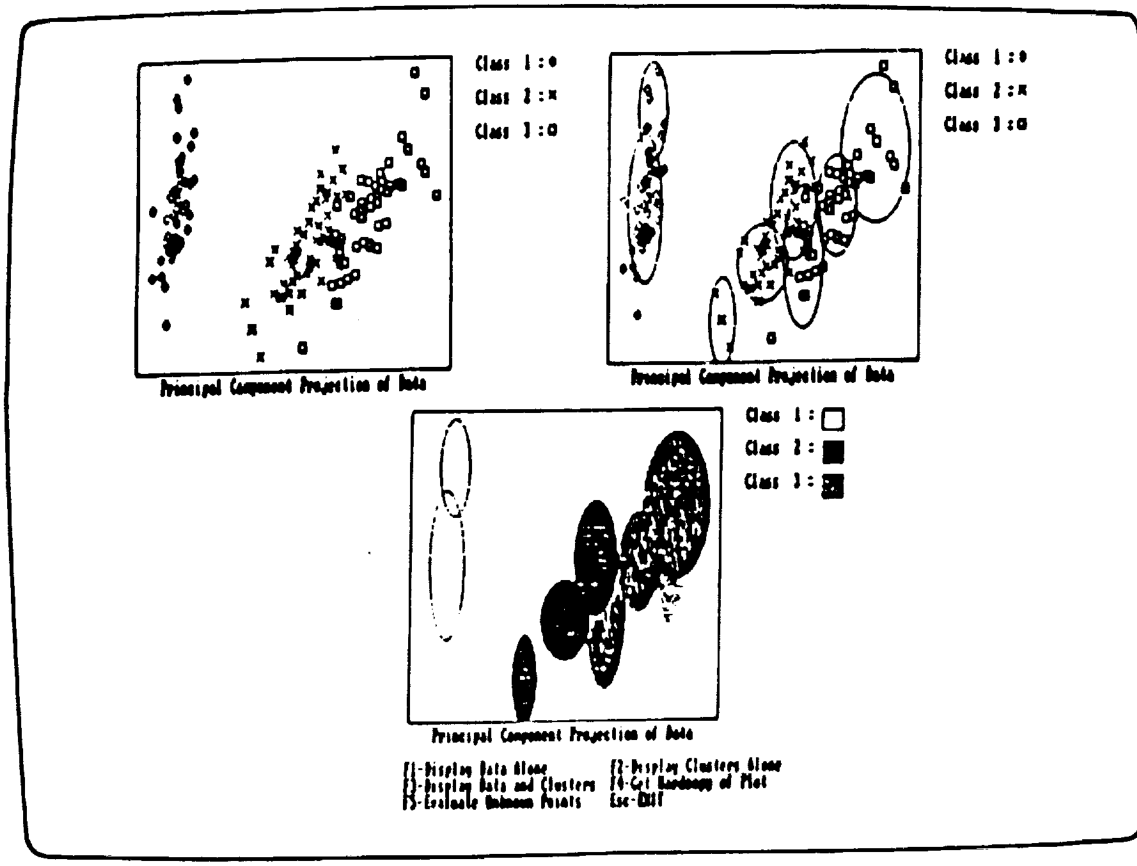
Fig. 4


Channel Number Is 1
F1 Select Channel
F2 Create DAC Curve
F3 Display DAC Curve
F4 Save DAC Parameters
F5 Recall DAC Parameters
F6 Select DAC Options
F7 Exit
Create DAC Curve
Cursor Controls:
Move gate right
Move gate left
Increase gate length
Decrease gate length
Find peak in gate
End Draw DAC curve
Esc Discard DAC and exit
Position transducer at point
Gate Start (μsec): 50.40
Gate Length (μsec): 1.24
Next sequence number: 1
y: mv/div
x: μsec/div
44.00 μsec delay
Scan Coord: 1= .000 2= .000 3= .000
Rectify (-) Freeze (+)


Channel number: 1
DAC Parameter File: test.DAC
100
80
60
40
20
SCREEN HEIGHT (%)
44.00 45.28 46.56 47.84 49.12 50.40 51.68 52.96 54.24
TIME (MICROSECONDS)
Sample Rate (MHz): 25.0
Pulser Atten. (dB): 0
Receiver Gain (dB): 7
Delay (μsec): 44.0
Length (μsec): 10.2
Length (pts): 256
No. of DAC points: 7
1 44.96 27
2 46.32 40
3 47.32 73
4 48.44 87
5 49.76 73
(More)
PgDn - Next Page ESC - Exit

TestPro™ DAP ENHANCEMENT (cont'd). . .

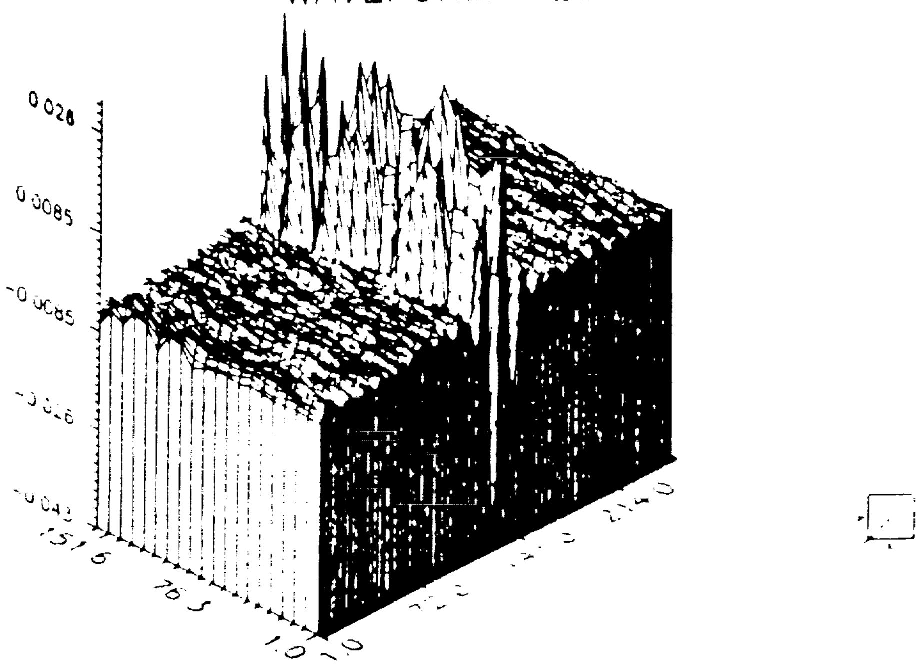
CLuSTERING (CLS) MODULE



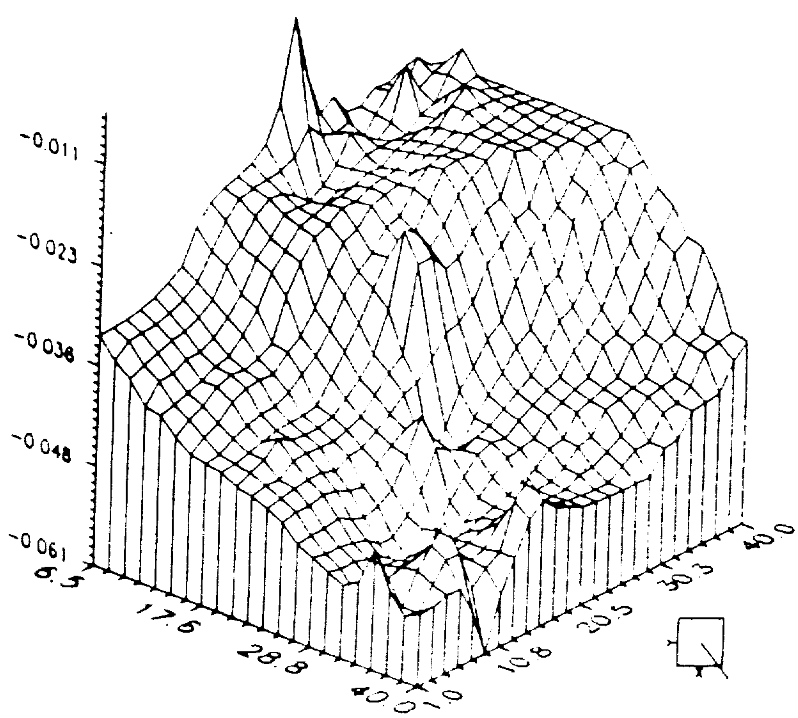
Infometrics

3 - D PLOTTING

WAVEFORM PLOT



WAVEFORM FEATURE MAP



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SIGNAL PROCESSING / FILTERING

Input File: \testpro\WAVUNC.KB1
Output File:

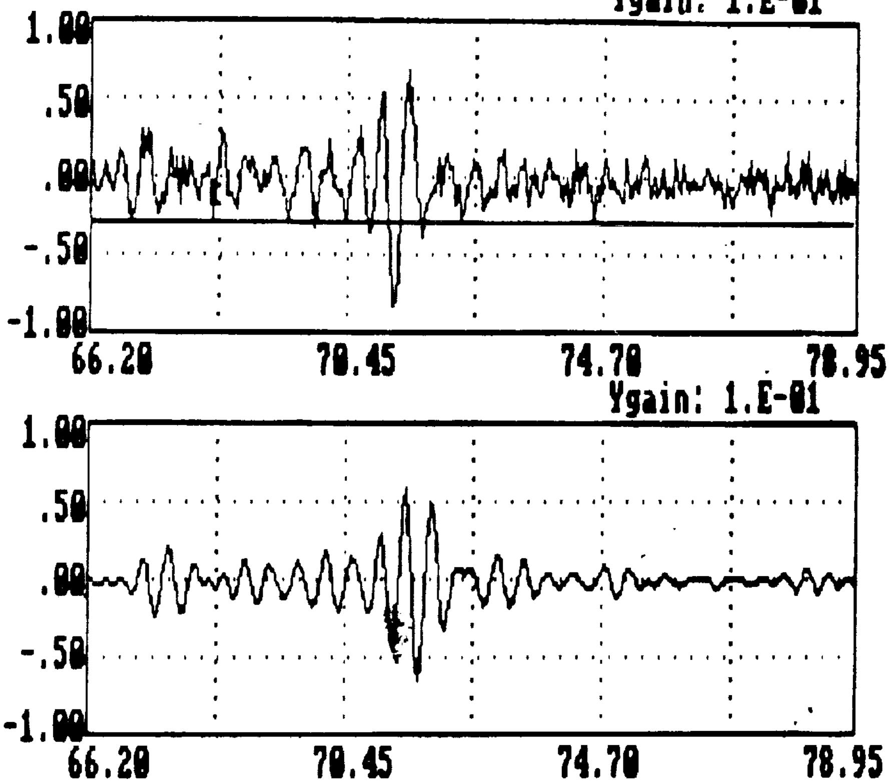
12-Jul-88

SIGNAL PARAMETERS

Seq. No.: 1
Samp. Rate: 20.00
Gt Strt (pts): 1
Gt Strt (μsec): 66.20
Gt Lng (pts): 256
Gt Lng (μsec): 12.75

ANALYSIS PARAMETERS

Minimum FFT Length: 128
Beg Freq (MHz): .0
End Freq (MHz): 10.0
Log Spectrum: NO
Taper Type: COSINE
Window Type: RECTANGULAR
Filter Type: BAND PASS
Cutoff Freqs: 1.8, 3.0



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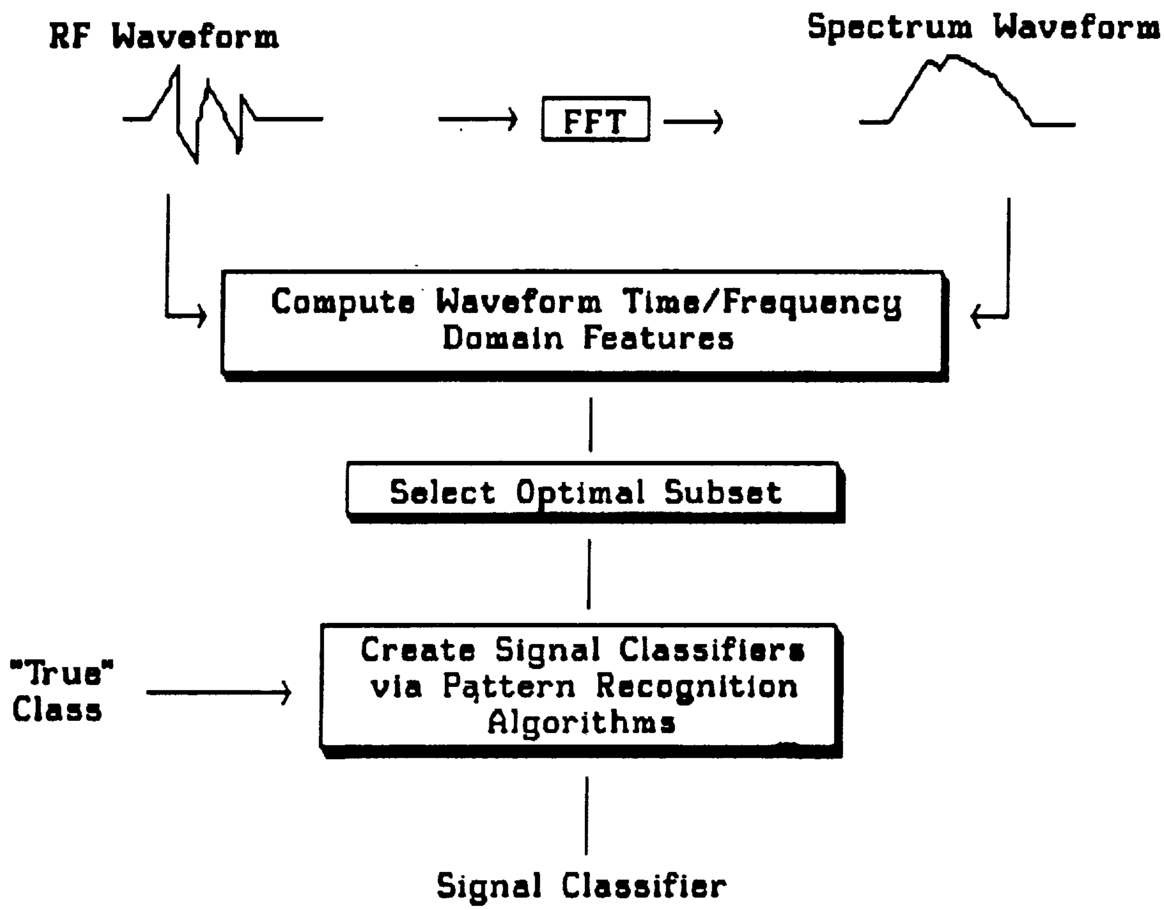
Automated Flaw Classification

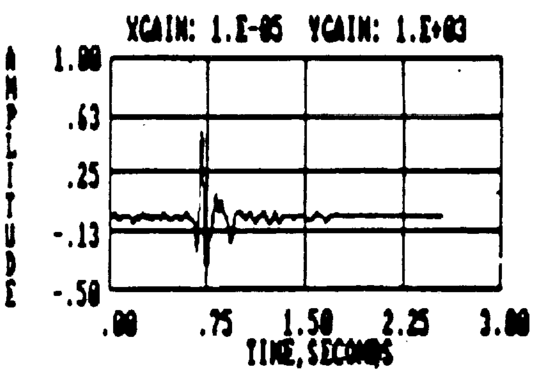


TestPro™ FCE ENHANCEMENT (cont'd)...

ANALYSIS (ANL) MODULE

Number of Classes 3
Optimum Number of Features 4
Waveform ID CA1002
True Class 1

CLASS 1:CRACKS
CLASS 2:COUNTERBORES
CLASS 3:ROOTS



Class Probabilities (%)

CLASSIFIER	CLASS 1	CLASS 2	CLASS 3
SINGLE GAUSS	98.0	1.0	.0
FISHER DISC.	91.0	7.0	1.0
5 PT. NEAR NEIG.	80.0	20.0	.0
7 PT. NEAR NEIG.	85.0	14.0	.0
11 PT. NEAR NEIG.	88.0	11.0	.0

Infometrics

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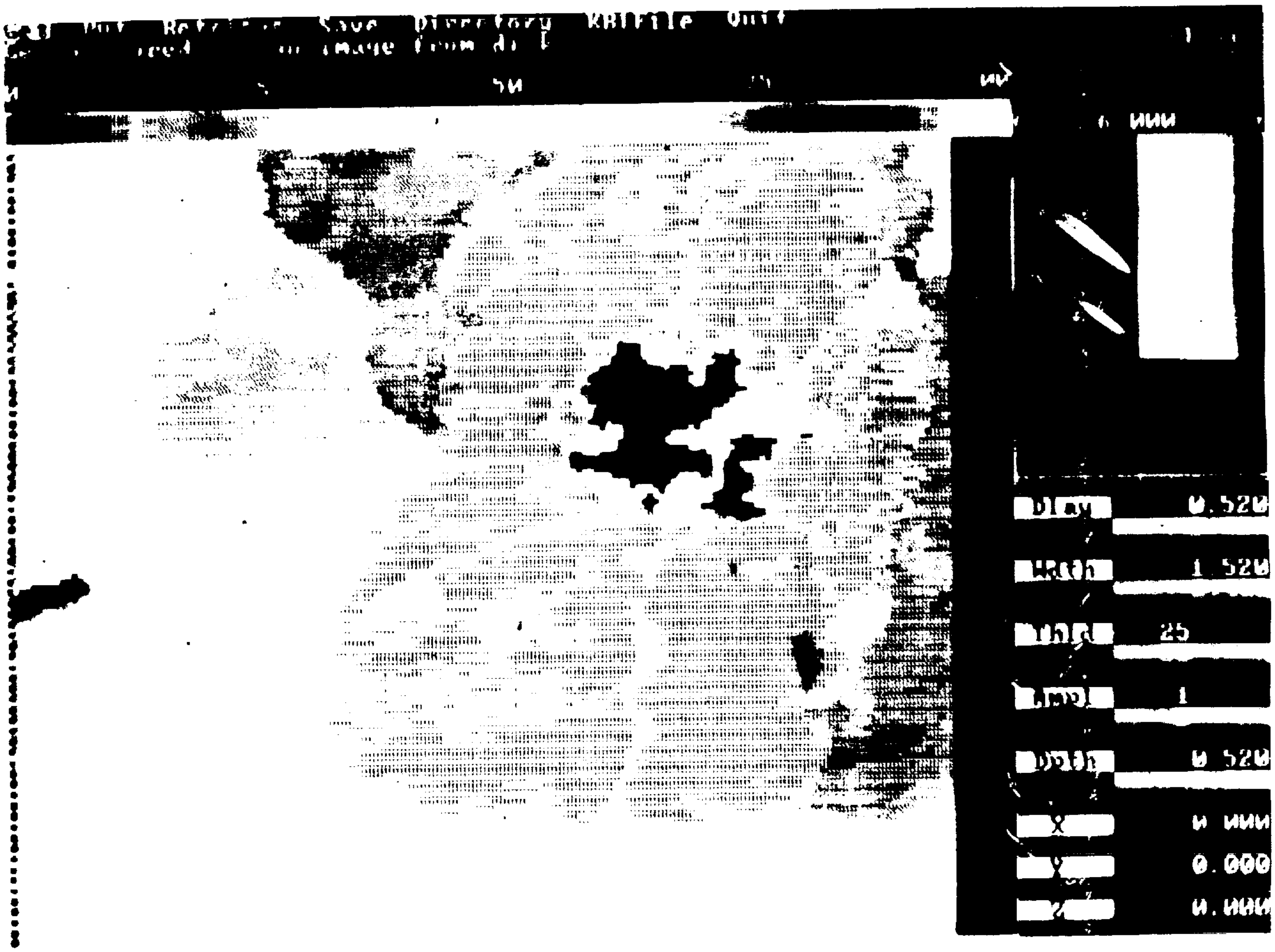
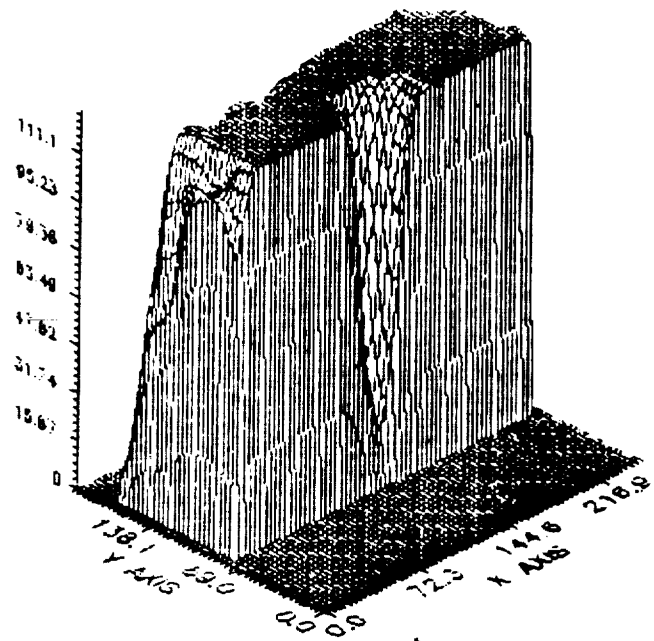
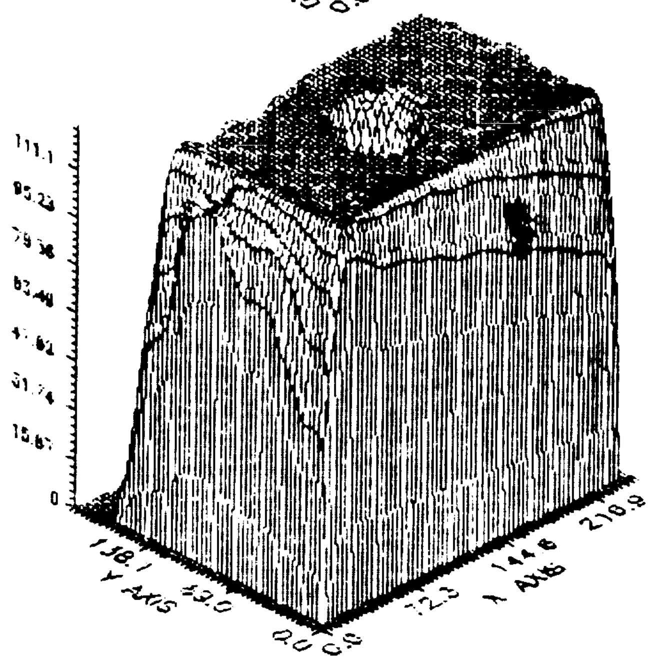
EXAMPLE OF TWO DIMENSIONAL DISPLAY OF DEFECTS USING TESTPRO



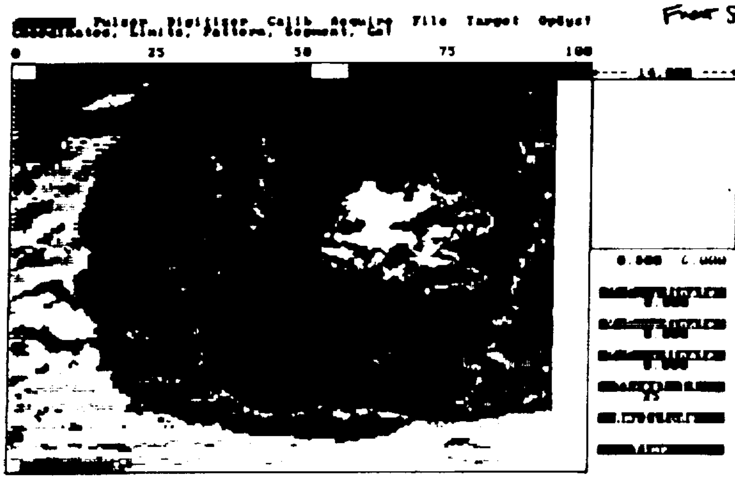
EXAMPLE OF TWO DIMENSIONAL DISPLAY OF DEFECTS USING TESTPRO

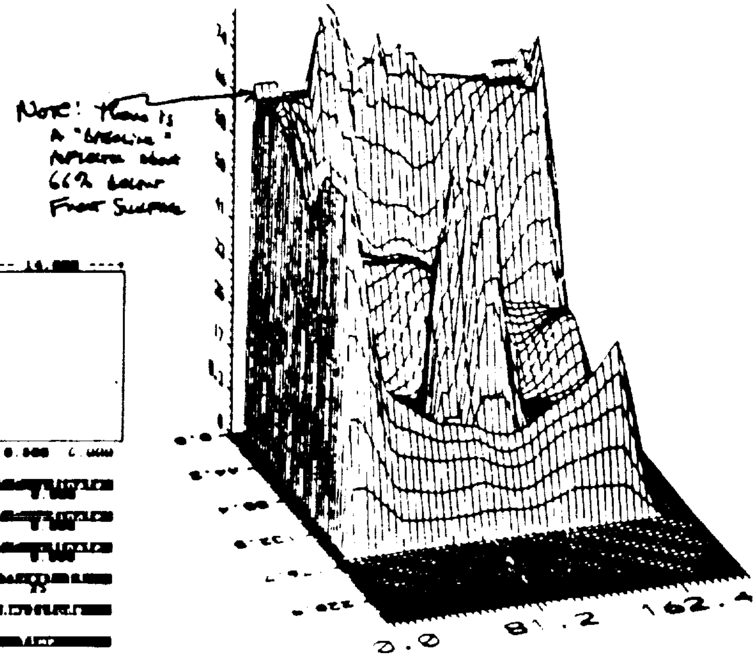
C - SCAN.....3 -D VIEWS

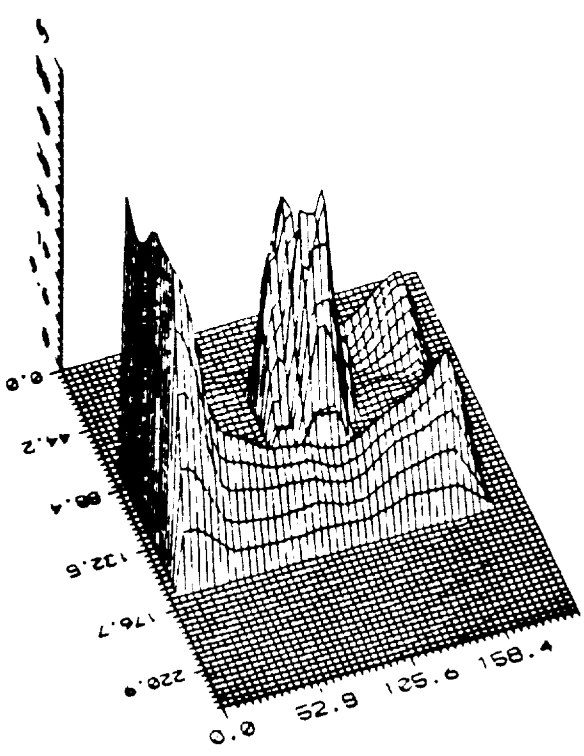


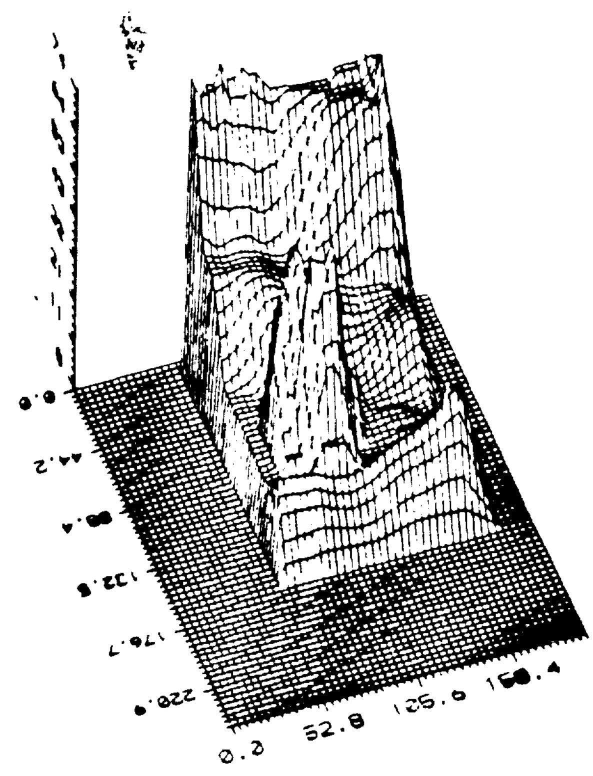


Composite-Impact Damage- ToF









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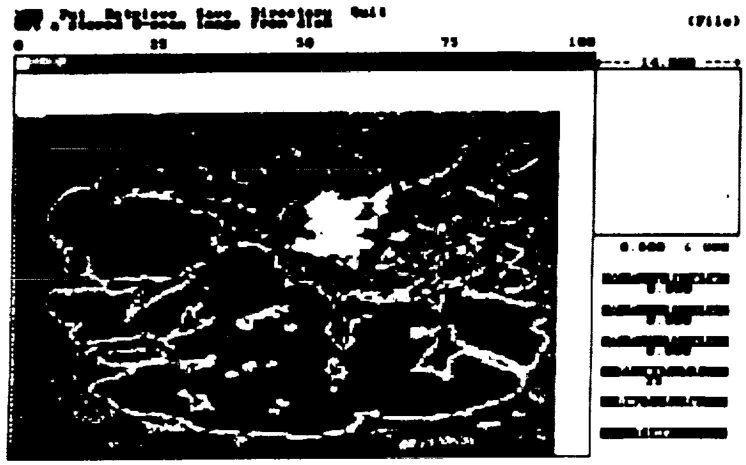
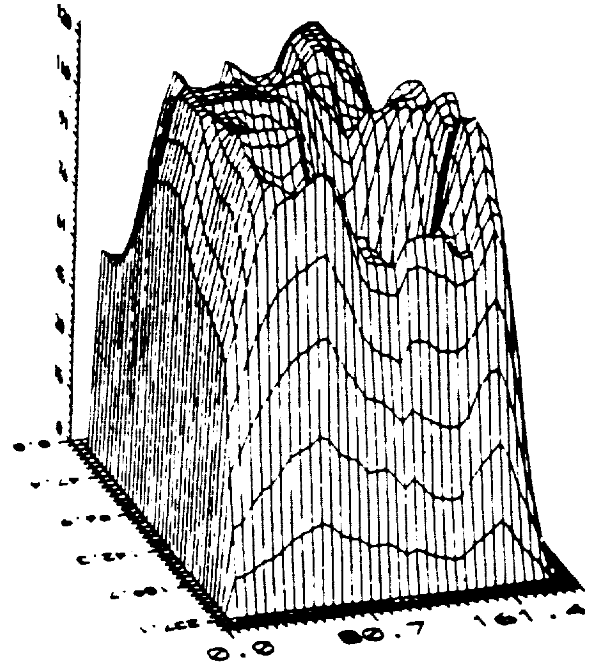
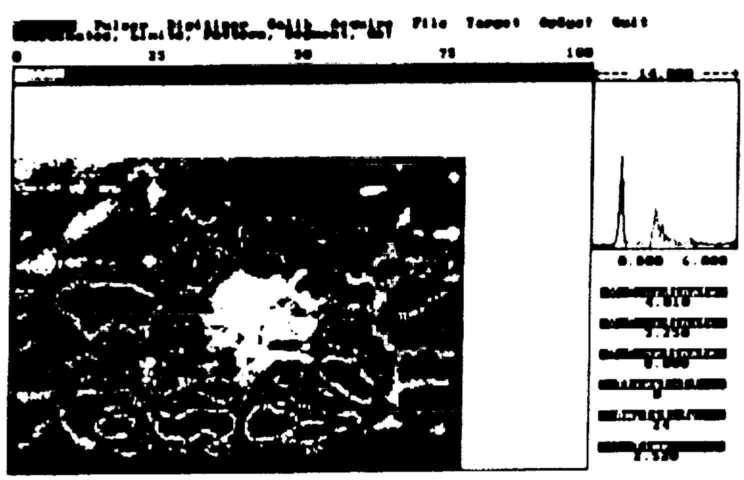
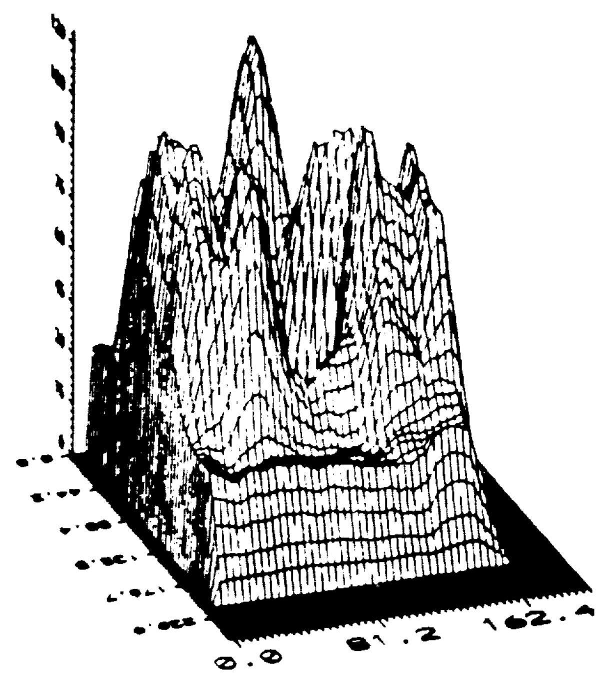
Composite-Impact Damage - Amp.





Composite-Impact Damage - Reduced Amp.





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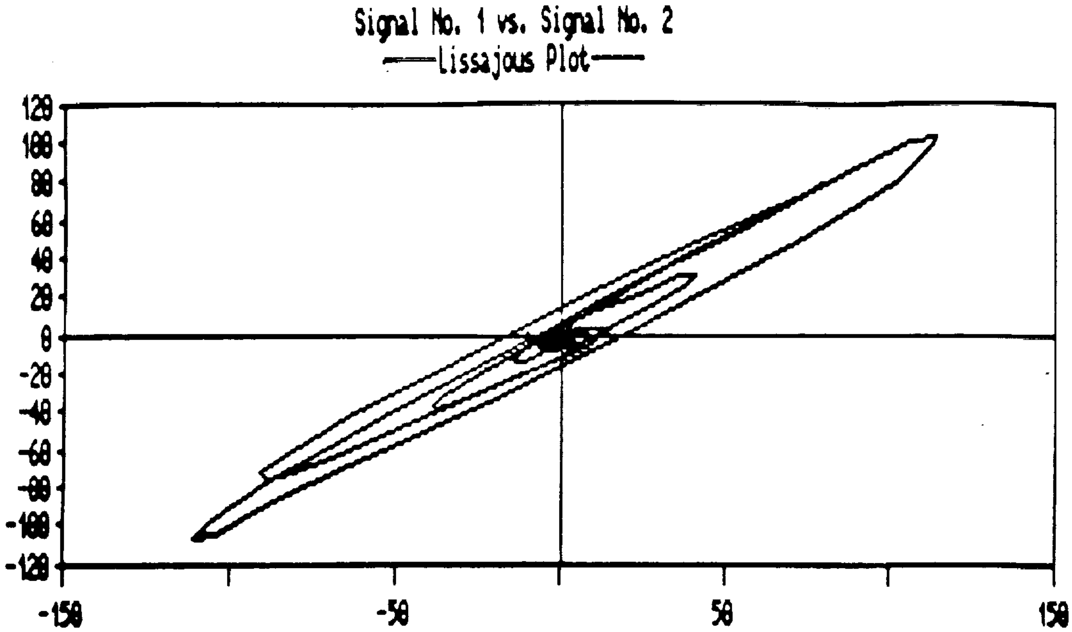
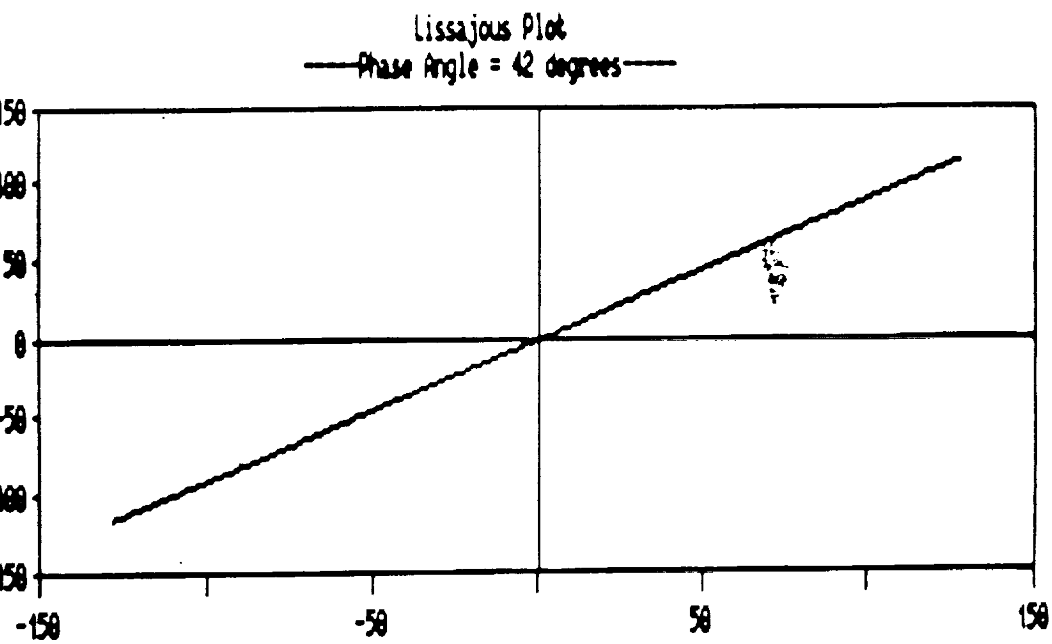

Signal No. 1 vs. Signal No. 2
——Lissajous Plot——
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-150
-50
50
150


Lissajous Plot
——Phase Angle = 42 degrees——
150
100
50
0
-50
-100
-150
-150
-50
50
150

SUMMARY

- PC-Based Signal Processing is Revolutionizing UT Inspection

- NDE Data are Pieces of Information -- PCs are Information Management Systems

- Changes can be made Relatively Easily because these Instruments are Software-Based

- Main Benefits to User include.....
  - -- Better QC of Field Inspections
  - -- Elimination of 3rd Party Re-Inspections
  - -- Minimize Reliance on Field Personnel as Signal Interpreters

- These Systems Represent the Next Generation of NDE Instruments