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NEW AND REFINED NONDESTRUCTIVE TECHNIQUES FOR GRAPHITE BILLETS AND SHAPES

A. E. OAKS

GENERAL ELECTRIC COMPANY

TECHNICAL REPORT AFML-TR-70-212

FEBRUARY 1970

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FOREWORD

This is the first year's final report in partial fulfillment of contract F33615-69-C-1623. This work is being carried out under project 7351 of the Processing and NDT Branch, Metals and Ceramics Division of the Air Force Materials Lab. Mr. William Shelton, MAMN, is the AFML Project Engineer.

This report summarizes the progress to date and presents plans and recommendations for the remainder of the program.

This work is being conducted within the Aeromechanics and Materials Laboratory of the Research and Engineering Department of the Re-entry and Environmental Systems Division, General Electric Company. The principal investigator and author of this report is Arthur E. Oaks of the Materials Performance Laboratory of the Materials Laboratory Operation. Other contributors to this work are R. Stinebring, P. Bolinger and E. Balbirnie. Companies cooperating in procuring special materials for this work are Union Carbide-Parma and POCO Graphite, inc.

This technical report has been reviewed and is approved.

Thomas D. Cooper
Chief Processessing and NDT Branch
Metals and Ceramics Division

ABSTRACT

This report summarizes the first year's effort to develop more sensitive techniques for detecting and evaluating flaws in graphite. On the basis of preliminary studies, it was concluded that the potential areas of improvement in the state-of-the-art lay both in the interrogative and interpretative aspects of NDT - that is in the techniques of introducing the test energy and generating the test signal on one hand, and extracting it from other non-information bearing or noise signals on the other. In regard to improved interrogative techniques particular emphasis was placed upon developing a better understanding and control of ultrasonic focused pulse echo inspection techniques to provide maximum response to small defects and the demonstration of the feasibility of delta scan ultrasonic inspection for ATJ-S and AXF-9Q grades of graphite. Other areas of interest for this work were an investigation of laminographic X-ray techniques and a basic definition of eddy current parameters leading to a possible application of pulsed eddy current techniques to graphite inspection. In the area of interpretation, primary emphasis was on improved techniques for the delination of small defects on x-ray images and the application of signal processing, especially spectrum analysis, techniques for analyzing the ultrasonic responses received from various types of defects in graphite. Results of the first year's work have defined the limitations of "conventional" pulse echo testing and demonstrated the basic feasibility of delta inspection for graphite inspection. A listing of advanced techniques for x-ray film enhancement is also included.

Next year's work will explore more fully the area of utility of the delta system and spectrum analysis for ultrasonic inspection. Efforts will also be made to evaluate more fully the capabilities of a modified laminographic for advanced applications such as graphite bonded to pyrolytic graphite for nose tips and rocket nozzles.

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SUMMARY OF EXPERIMENTAL STUDIES

The intent of this program is to evaluate a number of advanced ~~NDT~~ approaches. These covered a variety of interrogative techniques in the general areas of ultrasonic, radiographic and eddy current inspection. In addition, several potentially fruitful approaches to improved interpretation of the signals produced by these methods were evaluated. The main section of this report covers this effort in detail. This section is intended to present a short summary describing the individual techniques considered and an appraisal to date of its potential for graphite inspection.

NONDESTRUCTIVE TEST METHODS ULTRASONICS

Focal Plane Inspection

Advantages

Adaptable to all present ultrasonic test systems used for graphite inspection. Provides maximum sensitivity obtainable in shapes as well as flat specimens.

Disadvantages

Requires C scan capability for permanent records. Subject to degradation by inherent noise level in graphite so applicability is best in fine grain materials. Focal plane of transducer necessary extends only one to two inches deep so value of application to large billets is questionable. Shallow depth of field of focal plane ($\sim 1/4"$) will necessitate multiple inspection for best results.

Resolution & Sensitivity Factors

In ATJ-S, flat bottomed holes 0.030" dia. can be detected. In AXF-9Q sensitivity to flat bottomed holes is $\sim 0.015"$ dia. Analysis of sonic reflection phenomena indicates individual spherical pores need to be somewhat larger for equivalent response.

Ease of Interpretation

In AXF-9Q, response from artificial defects is quite strong with a minimum of spurious signals. In ATJ-S also get strong responses but internal noise degrades total quality of inspection.

Potential for Application of Signal Processing

Excellent. Transducer signal can be easily picked up for outside analysis of phase and spectral characteristics. Degree of improvement may be quite substantial since material noise signals appear to have different characteristics than true defects. The use of better quality instrumentation will also eliminate nonlinearity and other forms of test unit induced signal degradation.

Implementation Problems

Basic approach can be readily implemented at low cost on all immersion test systems. For more refined analyses at least one high frequency (~15 MHz) oscilloscope is needed to isolate defect signals. Good standards are always a problem.

DELTA SCAN

Advantages

Appears to eliminate front and back echoes and much of baseline noise so that the only signals received come from artificial defects. Delta angle does not appear to be critical (within limits). Can be adapted to immersion systems in use today at very low cost. Mode conversion aspects may eliminate problems from material noise in output.

Disadvantages

Requires C scan capability for permanent records. Awkward test setup slows analysis. Variable velocity characteristics may create problems in defining location of defects.

Resolution and Sensitivity Factors

Not yet determined. Tests still in progress. Analysis underway to determine effects of defect shape on results obtained.

Ease Of Interpretation

Elimination of many background signals improves ease of interpretation in AXF-9Q. Degree of improvement in ATJ-S not yet determined.

Potential for Application of Signal Processing

Would appear to be quite good. Mode conversion aspect of test may provide unique defect signature as opposed to material noise. Analytical capabilities applied to focal plane studies are applicable here. Exact potential now being evaluated.

Implementation Problems

Need special delta scanner. May require auxiliary capabilities for definitive analysis. Good standards will be a problem.

ACOUSTIC HOLOGRAPHY

Advantages

Permits visualization of ultrasonic beam and information in it.

Disadvantages

Currently unable to work with highly attenuating/scattering materials
Needs further improvement for graphite

RADIOGRAPHY

LAMINOGRAPHY

Advantages

Can be used to isolate small volumes of material for more definitive detectability, display and analysis. Should improve detectability of smaller flaws in structure.

Disadvantages

Requires special setup and equipment for implementation. Adaptability to shapes and very thick sections uncertain. Slower than conventional x-ray methods and will require several exposures for complete evaluation of material.

Advanced IITRI system is capable of resolving 0.7 mil cracks in printed circuits and has 4 mil vertical resolution. For thicker sections (~ 1 to $3''$) degradation caused by scatter may be limiting factor.

Ease of Interpretation

Superior to conventional radiography since ratio of defect thickness to section thickness is improved and confusion of superimposed defects is removed.

Potential Application of Signal Processing

Films can be treated by contrast enhancement methods (see next page). Non-film techniques using instrumentated detectors could be adapted for remote readouts.

Implementation Problems

Requires precision assembly for optimum performance.

FILM ENHANCEMENT

Advantages

Can easily double percent sensitivity obtainable. Many degrees of sophistication available. Greatly improve ease of inspection. Does not damage or alter original film.

Disadvantages

Cost of some units is high. X-ray techniques must be carefully performed to permit maximum freedom from scatter, fog and other sources of image degradation on film. Has all basic deficiencies of radiography for crack detection.

Resolution and Sensitivity Factors

Depends on quality of original film. With good film, output limited only by sensitivity of eye to image changes and ability of detector to sense input changes. Film unsharpness is limiting factor for higher voltage applications.

Ease of Interpretation

May require some special training to relate enhanced images to original.

Potential for Application of Signal Processing

Many techniques now used on more sophisticated approaches. Edge enhancement, color conversion and digital analysis have all been used in these studies. Holographic interferometry appears to have only limited potential.

Implementation problems

Basically none except that some methods are limited to film densities below 3.0.

EDDY CURRENT

Advantages

Best method for near surface defects. Fairly easy to apply. Adaptable to curved surfaces. Many advanced techniques available.

Disadvantages

Interpretation affected by non-discrepant material variations. Cost of equipment fairly high. Development of special techniques often requires personnel with advanced training. Graphite structure complex and conductivity low which appears to reduce response as compared to metals.

Resolution and Sensitivity Factors

Depth of penetration function of frequency. Advanced system now being built. Evaluation not yet started.

Ease of Interpretation

Will need good standards and understanding of response to evaluate changes occurring.

Potential for Application of Signal Processing

Excellent. Many advanced techniques available. Multifrequency and pulsed techniques look very promising.

Implementation Problem

Instrumentation still in state of development. Cost is relatively high and may require specific design for graphite inspection.

SIGNAL PROCESSING TECHNIQUES

FREQUENCY DOMAIN ANALYSIS

Characterization of Information

Breaks down composite AC signal from transducer or receiver into individual frequency components. Spectra from different internal conditions tend to be different, allowing better discrimination between real and spurious signals.

Interface Problems

Requires additional instrumentation to develop and display spectra. Impedance matching very important.

Readout Problems

None, if system properly matched.

Applicability of Machine vs. Human Interpretation

If signals of interest can be characterized, computer interpretation is possible. This also would allow scanning. Human interpretation is slow but necessary in beginning. Off line processing is possible with taped or photographed displays.

Degree of Improvement Possible

Potential is good for enhancing interpretation and understanding of ultrasonic and possibly eddy current data.

SIGNAL INTEGRATION

Characterization of Information

Depends on random nature of electronic noise to integrate to zero while true signals are additive.

Interface Problems

Requires special instrumentation. Also needs special scanning techniques to eliminate background noise in material.

Readout Problems

Work reported by Boeing indicates results are fairly straightforward if properly implemented.

Applicability of Machine vs. Human Interpretation

Output can be fed into printer for C scan map or visual interpretation of scope output.

Degree of Improvement Offered

In cases where background noise reduces signal level to uninterpretable levels, considerable improvement may be possible especially for ultrasonic inspection.

RADIOGRAPHIC SPATIAL FILTRATION

Characterization of Information

Acts to eliminate respective background information from radiographs of complex materials thus increasing sensitivity to material differences.

Interface Problems

Completely off-line. Must be able to characterize signals of interest and those to be eliminated. Not felt to be applicable to graphite but might be useful for composite evaluation.

INTRODUCTION

As a result of studies leading to the development of advanced materials for high temperature applications, it became quite evident that the potential of graphite for such use was not being realized. In spite of much work to develop improved species of graphite and the use of advanced NDT techniques to predict materials properties, fabricated sections were still failing at thermal and mechanical stress levels well below those expected. Detailed examination of the failed parts showed clearly that in many cases, failure initiated at the site of a pre-existing small defect such as a crack or void in the graphite structure. Although considerable effort has been expended to improve the capabilities of the state-of-the-art techniques now used for flaw detection in graphite these have still proved to be inadequate for the needs at hand. Consequently, it was agreed that new approaches to flaw detection in graphite should be investigated. The purpose of this program is to perform such an investigation. This report is a summary of the studies performed and progress to date.

BASIC TEST APPROACH

The GE program for developing new and refined NDT techniques for graphite is based on several premises.

The first of these is that any NDT method usually can be divided into two separate and often quite distinct phases - interrogation and interpretation - and that such a separation can lead to a variety of advantages.

Interrogation deals with the different techniques for introducing the various forms of energy used as the basis for most NDT methods into the material being tested and the generation of the particular energy-material interaction which creates the test signal desired for subsequent analysis and part disposition. Interpretation on the other hand deals with the treatment of the generated test signal to enhance and/or extract the desired information that is, in fact, the "test". In many cases interpretation is merely the looking at and mental analysis of some form of displayed signal.

This separation of an NDT method into these two areas opens up many possibilities for improved inspection procedures. In "interpretation", for example, it becomes possible to employ a wide variety of electronic and optical techniques for enhancing "signal/noise ratios," suppressing unwanted signals ("noise") or converting one desired signal into another which is more readily interpretable. In interrogation we can select basic approaches which are likely to create a maximized response from the condition being sought.

The second premise upon which this work is based is that although the enhanced methods developed will tend to improve the detectability of defects at the billet stage; their best area of application will be with the relatively thin sections of partially or finished machined parts when the condition sought represents a larger percentage of the gross volume inspected. While this represents a departure from the conventional NDT approach of moving inspection forward in the process, it also maximizes the chances of detecting those conditions which, to date, have been compromising graphite's utility for critical high temperature applications.

Because this program involves the evaluation of a wide variety of techniques, certain restrictions were necessary to keep it within manageable limits. Consequently, it was decided to place initial maximum emphasis on the ultrasonic aspects of interrogation and on those interpretative methods most suited to act as adjuncts to it. At the same time certain basic studies in radiography and eddy current techniques were to be undertaken so as to phase the positive aspects of the studies into the program downstream of the ultrasonic studies. The general timing of these efforts is shown in the attached flow charts which present the program plan for the two year duration of this contract. The rationale for the selection of the individual methods selected was described in great detail in the first quarterly report. This final report describes the progress recorded in evaluating the potential of the several approaches discussed at that time.

I SCOPE OF STUDIES

As described above, this program is to consider both the interrogative and interpretative aspects of NDT as applied to graphite. In the former aspect the objective is to look at methods which lend themselves to the inspection of relatively small, discrete areas or volumes of material in a larger specimen. In the latter we are working with techniques for extracting desired information from a complex signal. The objective of these studies is to improve the ability to detect flaws or discrepancies in graphite. Estimation of the significance of the conditions found in terms of performance capability reduction is not included in this work.

In regard to the interrogative studies the bulk of the efforts to date have been confined to ultrasonic studies. In this area three basic concepts were selected for evaluation:

- a. "Hislop" local plane inspection (1)
- b. Delta inspection (2)
- c. Acoustic holography (3)

As adjuncts to these studies three interpretative methods were also selected for prime consideration:

- a. Frequency domain analysis (4)
- b. Signal integration (5)
- c. Schlieren studies (6)

Other interrogative/interpretative techniques selected for investigation were:

- a. Laminography (7)
- b. Contrast enhancement (8)
- c. Pulsed eddy current techniques (9)

Each of these methods has been described in the literature but with one or two exceptions they had not been applied to the problems of graphite. It was felt that each of them offered some advantage in interrogating the material and/or interpreting the results. Short discussions and illustrations of the principles behind each of these methods are contained in the discussion section of this report.

In the performance of these studies certain modifications were made to existing equipment to increase their utility for this program. Along this line a precision scanner and small billet holder were assembled and alterations were also started on our ultrasonic generating equipment. The latter has as its objective the improvement of our ability to capture unprocessed and semi-processed signals for external analysis. These modifications are described in the text.

II MATERIAL

Although this work is intended to be applicable to all grades of graphite of aerospace interest it was obvious that from the practical point of view only a few types would be specifically considered. Consequently, it was decided to limit the study to one fine grain isostatic grade graphite and fine-to-medium grain compression molded grade of graphite. POCO AXF-9Q and Union Carbide ATJ-S respectively were designated as being representative of the grades of most interest for aerospace applications. From the NDT point of view, the structural differences in these materials created their own special problems, particularly in ultrasonic inspection. ATJ-S is acoustically quite noisy which, in practice limits the highest frequency used for testing to about 2 ½ MHz. (Figure 1). For thicker sections this value is reduced to about 1 MHz. AXF-9Q is less dispersive so that higher frequencies can be used. In this material 2 ½ MHz can be used for 5" dia. billets and even 5 MHz for thinner sections. All other things being equal, defect sensitivity increases with frequency so it always is desired to use the highest one permitting unambiguous interpretations.

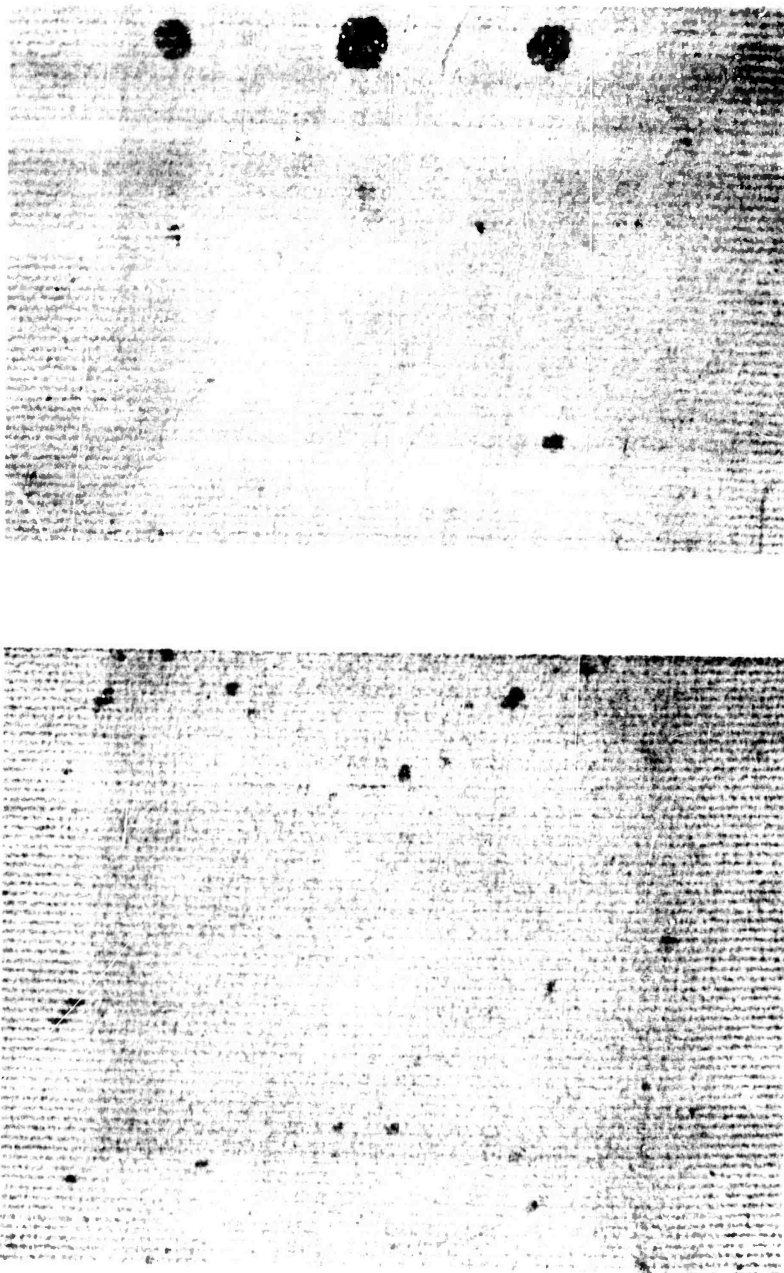
While normal commercial billets of these grades do, on occasion, exhibit natural defects, it was decided to maximize the chances of having "natural" defect conditions in the material by having special "marginal" billets prepared for our use. For this purpose two billets of each grade were to be prepared by slightly under and over filling the molds to produce close-to-spec. limit low and high density material. A third "standard" billet of each grade was also procured.

Both the normal and "special" billets were to be processed together so that a considerable perturbation was introduced into the timing of the studies anticipated. The AXF-9Q billets took approximately six months for delivery while the ATJ-S billets were not delivered until nine months after the start of the contract. Therefore, in order to start work it was necessary to procure material from other sources. For this we were able to procure several 1" and 3" thick 8" diameter discs of ATJ-S from commercial billets procured for other programs in-house at the time. This upset the expected approach somewhat since it had been planned on the basis of developing basic relationships of the finer grained, less "noisy" AXF-9Q and then transferring the optimized techniques to the coarser, noisier ATJ-S.

Preliminary ultrasonic examination of these discs showed them all to have pronounced zonal velocity characteristics. In all cases a center zone approximately 3-4 inches in diameter having a transverse ultrasonic velocity ~ 7% slower than the outer zone was found. Furthermore at the interface of the two zones there was an annular ring 1/8" to 1/4" wide which completely absorbed the sound energy - it was acoustically dead (Fig. 2). These conditions created some problems in the subsequent studies but once their presence was known it was possible to work around them for most purposes. (See Below).

FIGURE 1

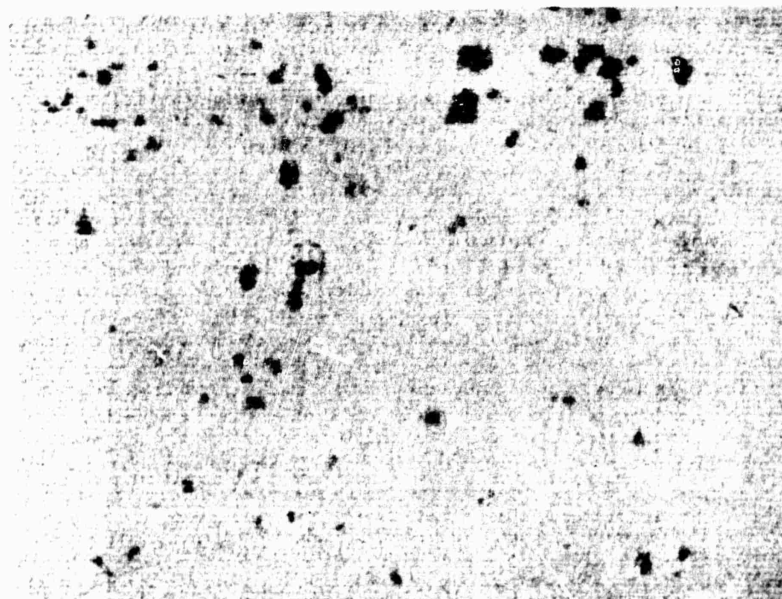
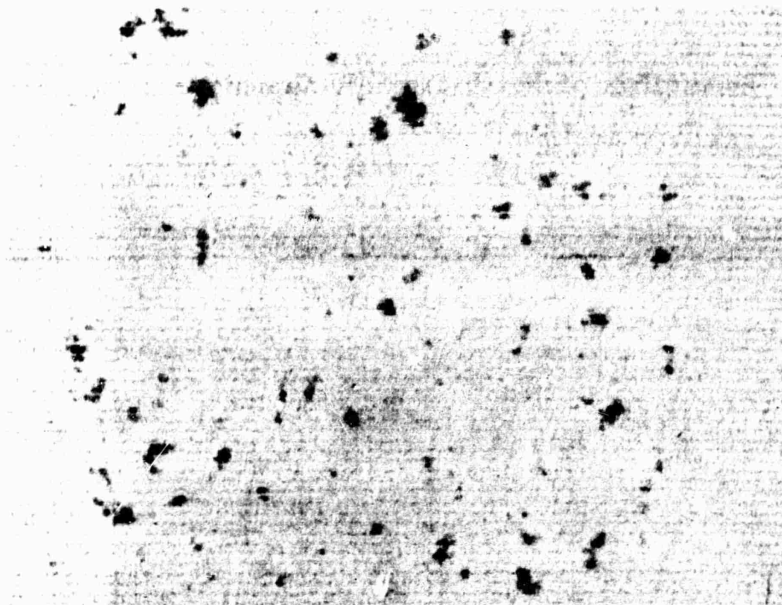
Recordings of Noise from ATJ Graphite



2 1/4 MHz scan of 1" slab of ATJ-S graphite

Run #3 Recording gate set for signals originating from 3/4" deep to back surface echo in material (Plane of flat bottom holes is 3/4" deep).

Run #4 Recording gate set for 1/2 - 3/4" (just in front defect signals)



Run 5 Recording gate set $1/4$ to $1/2$ " deep

Run 6 Recording gate set from just after top surface echo to $\sim 1/4$ " deep

All runs made with same transducer to material distance and control settings.

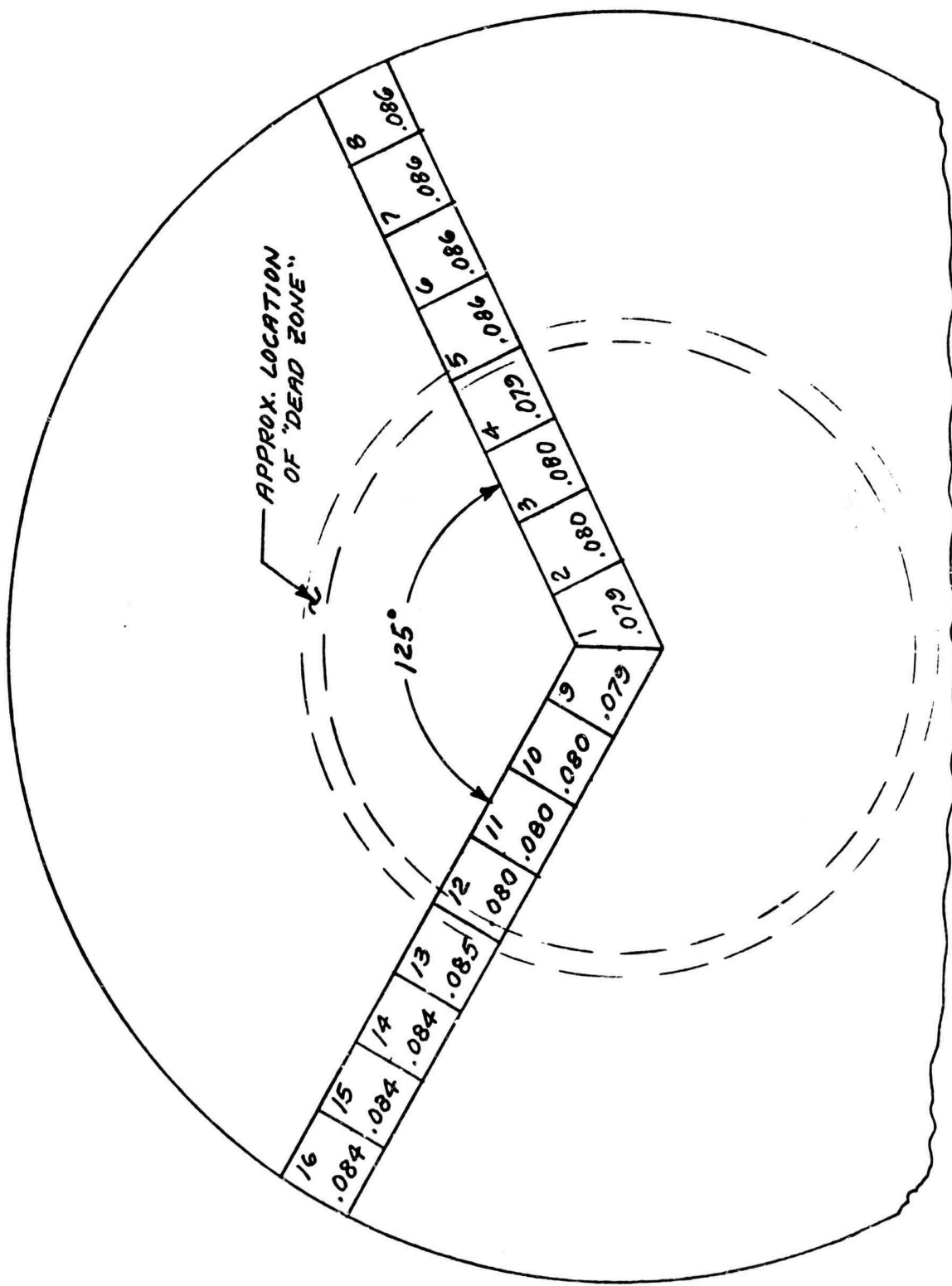
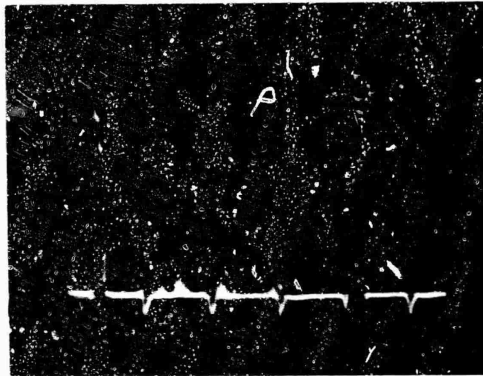


Figure 2a. Typical Longitudinal Velocity Variation in Reference Disc

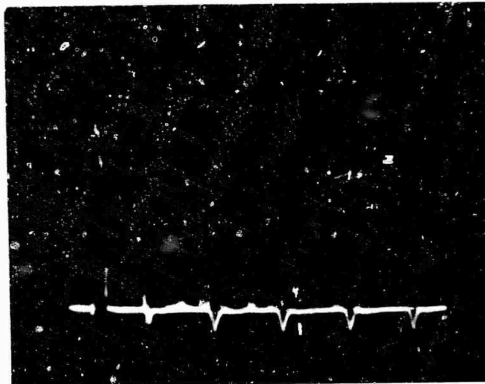
Figure 2b

Velocity Shift in ATJ-S Graphite Showing Dead Zone
Velocity shift illustrated is approx. 8%

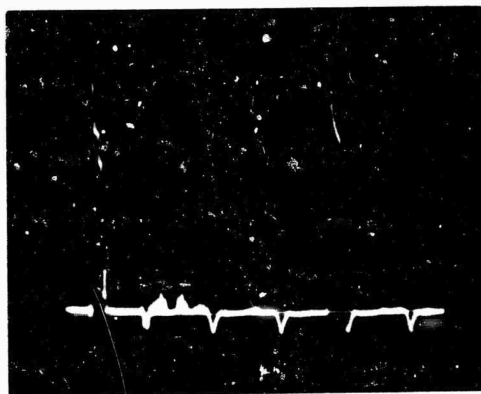
Outer Zone



Dead Zone



Inner Zone



III LITERATURE AND INDUSTRY SURVEY

In order to factor the latest advancements from other NDT organizations into this program, a formal literature and industry review was organized. The literature search which included surveys from DOD/AMMRC, NASA and AEC sources was largely conducted during the first quarter. Over 1,000 pertinent references were located and approximately 300 were ordered for permanent retention and are now available in our files. Most of these are unclassified and have been cataloged and indexed by subject so that reasonably efficient retrieval is possible. A small effort along this line can be expected to continue for the balance of this program.

The literature survey was designed to complement a parallel program of discussions with or visits to particular personnel conducting studies germane to the work. These visits are considered desirable since the personnel concerned are often more candid in person than in writing and written material may be as much as six months to a year late in being published. During this period discussions were held with representatives of a number of organizations concerned with advanced NDT to discuss their work and evaluate its utility to our interests (Table 1). These visits lead to several demonstrations or feasibility studies which will be described in more detail in the appropriate sections below.

TABLE 1

Organization Visited	Personnel Contracted	Purpose of Visit	Results
UCC-Parma	J. M. Criscione H. W. Townsend	Arrange for special ATJ-8 billets. Explain & discuss potential application of program.	Special billets provided.
FOOD	Dr. R. Wehrmann	Same as UCC	Same as UCC
GE-Syracuse	W. Fann D. Duffy	Discuss application of holographic techniques to this program	\$13,000 quote for small effort. Study deferred.
Army Material & Mechanics Research Center (AMMRC)	O. Gerricks	To arrange for spectral analysis studies	Studies indicate flaws create spectral differences in received signals.
Holotron, Inc.	R. Mattra	To arrange for acoustic holography studies	First studies inconclusive. More powerful unit needed.
Illinois Institute of Technology Research Institute (IITRI)	T. Moller	Further discussions on Laminography	Suggestions to improve GE prototype system. Action deferred.
Naval Ordnance Laboratory	D. Polansky	Discussion of spatial filtration techniques	Will try to arrange joint study at NOL
Naval Research Laboratory	H. Chaskalis	Discussion of ultrasonic equipment and schlieren system problems.	Enhanced awareness of equipment degradation problems
Metal and Thermit	R. Buckley	Discussion of schlieren system problems	
McDonnell Douglas	J. Cook	Discussion of general graphite NDT problems	Arrange information exchange program.
Spatial Data Systems		Demonstrations of advanced color enhancement method for radiography	Method looks very promising
NASA-MSFC	J. Beal	Discuss advanced NDT methods	Arrange information exchange program
Fanstrics, Inc.	L. Lynnworth	Discuss advanced ultrasonic methods	They will keep us up to date on advanced equipment and techniques as they develop.
Hortec, Inc.	K. M. King	Demonstration of advanced eddy current unit	Unit procured for advanced studies

PRELIMINARY MATERIAL QUALIFICATION

While the special ATJ-S billets have arrived too recently for any extensive evaluation work to be done with them, as noted above it was possible to begin the preliminary ultrasonic studies with other samples of this material. This velocity shift condition created a problem in setting up the ultrasonic tests of these pieces since the position of the back echo and of certain constant depth reference artificial defects would vary along the base line of the A scan presentation depending upon which zone was being inspected. Since the recording gate is fixed by a time reference to the front surface echo (and therefore does not vary from zone to zone for a constant transducer to surface distance) it was quite possible for a given defect indication to fall either inside or outside the gate depending upon which zone it was in. To prevent this situation from compromising the results of the tests it was necessary to open the gate wide enough to cover all contingencies. Since the focal plane technique (described below) may depend on precision gating to pick up the desired signals and exclude noise this condition definitely imposes some extra difficulty in implementing this technique. The extent to which this condition exists in the special material produced for this program remains to be seen.

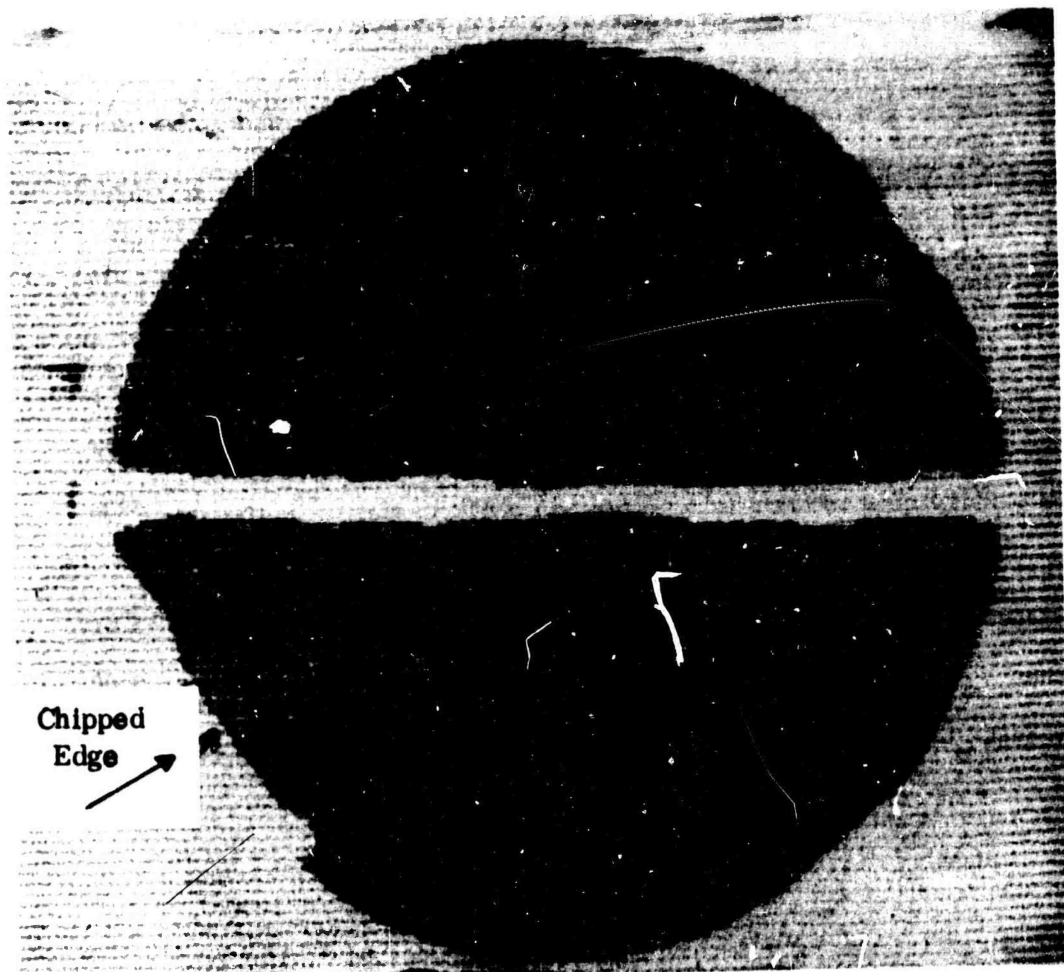
Preliminary inspection of the special POCO material showed no major surprises. At the start of the program we were able to obtain two AXF-5Q billets originally produced for the RESEP program which had been inspected and rejected by McDonnell Douglas. When these were received, the surfaces had been marked to indicate the location of the internal discrepancies which had been detected. No difficulty was experienced in duplicating the previous results. With our material 1" slices were removed from the top of each billet and given a preliminary inspection at 2 1/4 MHz with an amplifier gain just below that necessary to produce a saturated back echo signal. This condition was reached with a surprisingly low level of gain for each of the three billets. A recording gate was set under the back echo and adjusted to respond first to 30% and then 50% loss of signal. A second series of runs were made with the gate set between the front and back echoes and set to respond to any signal having an amplitude greater than 20% of full scale. At this gain setting no internal defect signals were received but the maps from the high density marginal billet and the "normal" billet did show small areas of 30-50% loss of back echo (Figure 3-5) Billet #2 also showed a slight ultrasonic velocity shift but not nearly as great as that observed with ATJ-S. The billets did show small differences one from the other in gain and gate settings needed to produce the optimum results and in the more formal studies described below it was necessary to factor these into the setups used. (Table II)

The three slices were sectioned diametrically and photographed at 53X and 212 x to determine if any macro differences existed, especially in the high attenuation area (Figure 5). While the grain sizes of the three billets were essentially the same, differences in the porosity levels did appear. As expected, the higher density billet #1 had the least. However, low density billet #2 and normal billet #3 were quite similar. Perhaps the fact that billet #2 was specially processed made some difference in the quality achieved.

TABLE 2

Billet No. (P.O. #U15817)

	<u>GE-NDT-1</u>	<u>GE-NDT-2</u>	<u>GE-NDT-3</u>
Type (by Vendor)	Higher flaw concentration than normal production	Higher flaw concentration than GE-NDT-1	Representative of normal aerospace quality production
Density, gm/cc	1.830	1.770	1.791
Graphitization temperature, °C	2900	2900	2900
Dimensions			
diameter, inches	5.016	5.016	5.017
length, inches	8.017	8.020	8.021
Alcohol spray test results	← no high porosity areas noted →		



NOT REPRODUCIBLE

Figure 3

"C" SCAN MAP OF 1" THICK SLAB OF AXF-9Q SPECIAL BILLET
#1 - RECORDING GATE SET TO RESPOND TO 30% LOSS OF
BACK REFLECTION

(Piece cut into semicircles pryer to this inspection for metallo-
graphic examination)

NOT REPRODUCIBLE

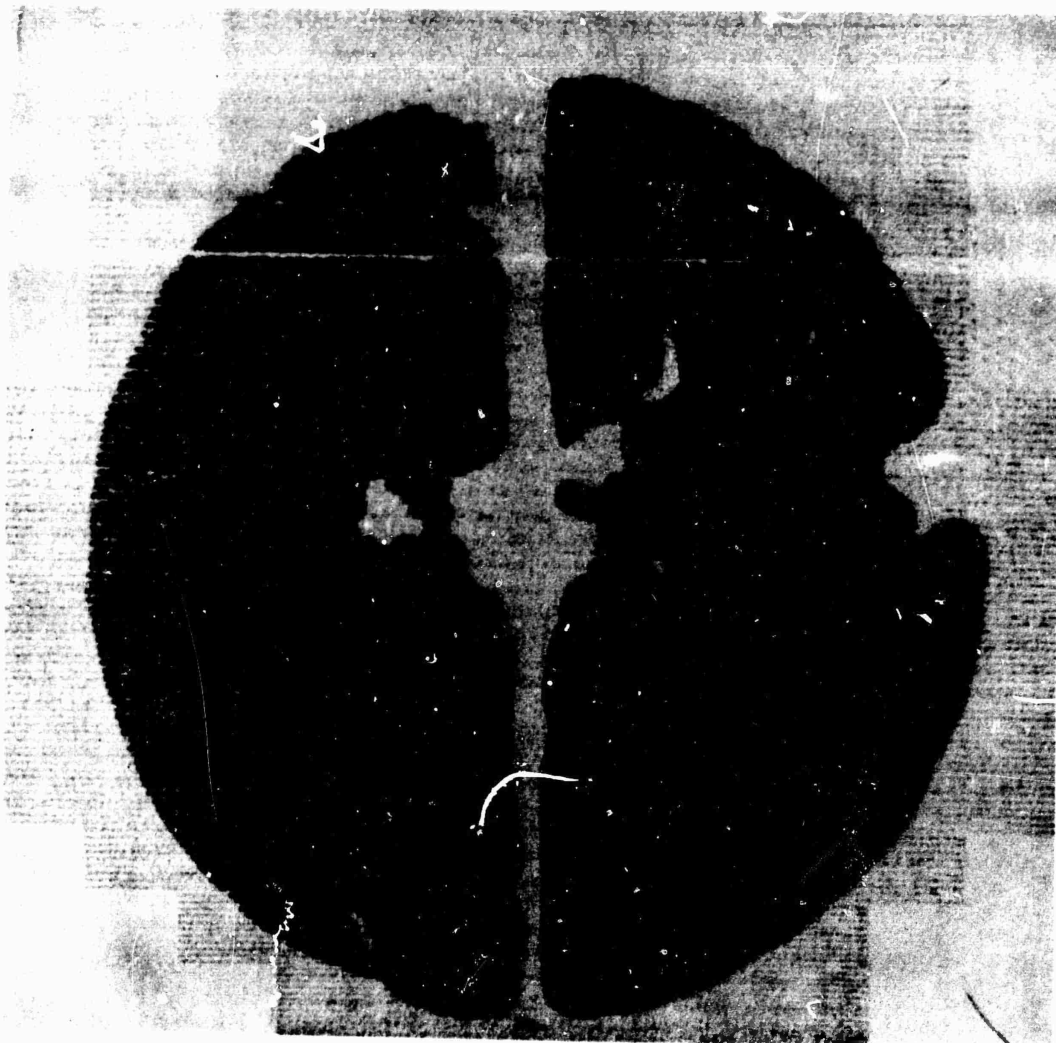


Figure 4

"C" SCAN MAP OF 1" THICK SLAB OF AXF-9Q SPECIAL BILLET #2
RECORDING GATE SET TO RESPOND TO 50% LOSS OF BACK REFLECTION

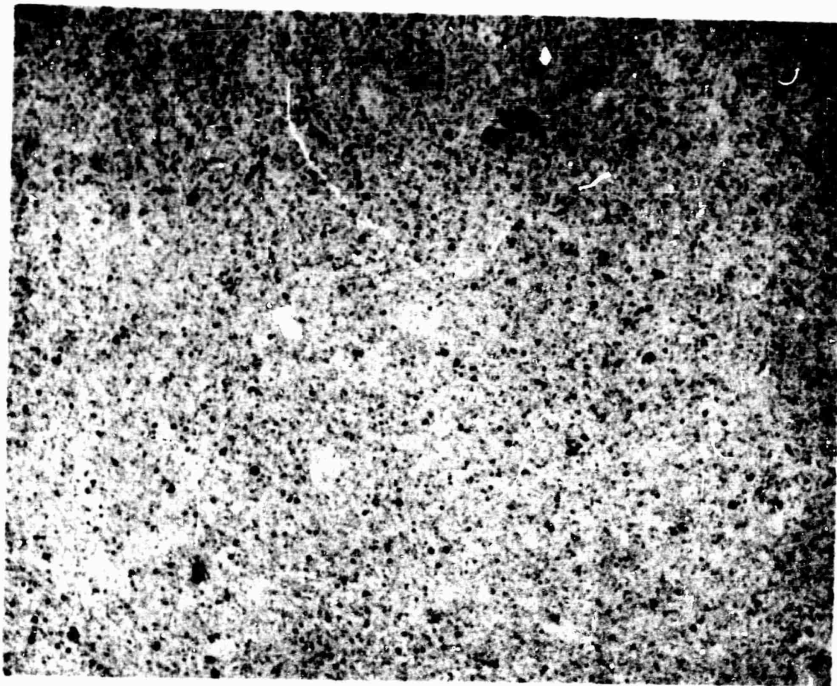
(Piece cut into semicircles prior to this inspection for metallographic examination.)



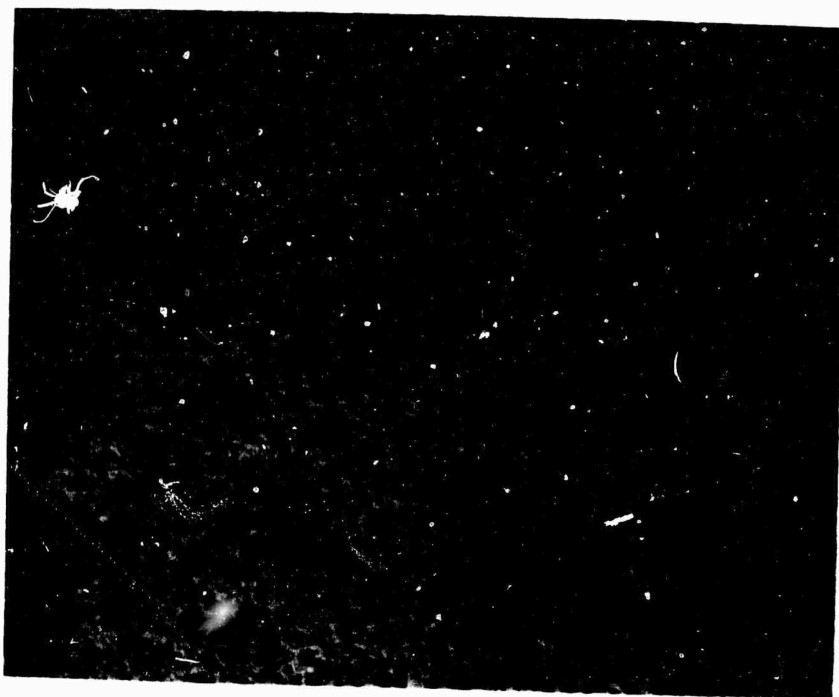
Figure 5

"C" SCAN MAP OF 1" THICK SLAB OF AXF-9Q SPECIAL BILLET #3
RECORDING GATE SET TO RESPOND TO 50% LOSS OF BACK REFLECTION

(Piece cut into semicircles prior to this inspection for metallographic examination.)



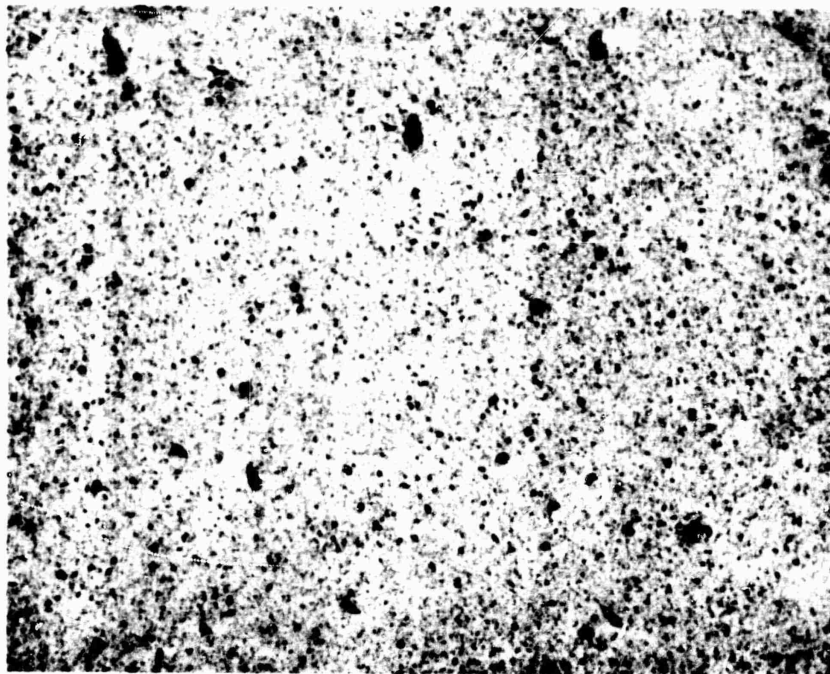
BILLET # 1
(53 X)



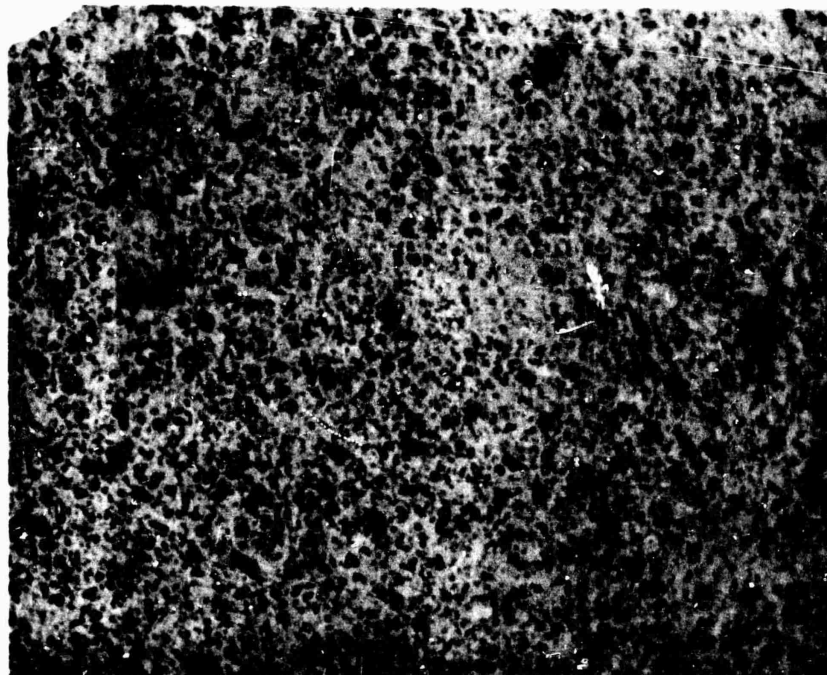
BILLET # 1
(212 X)

Figure 6

53X and 212X ENLARGEMENTS OF GRAIN STRUCTURE OF SPECIAL AXF-9Q BILLETS FABRICATED FOR THIS PROGRAM.



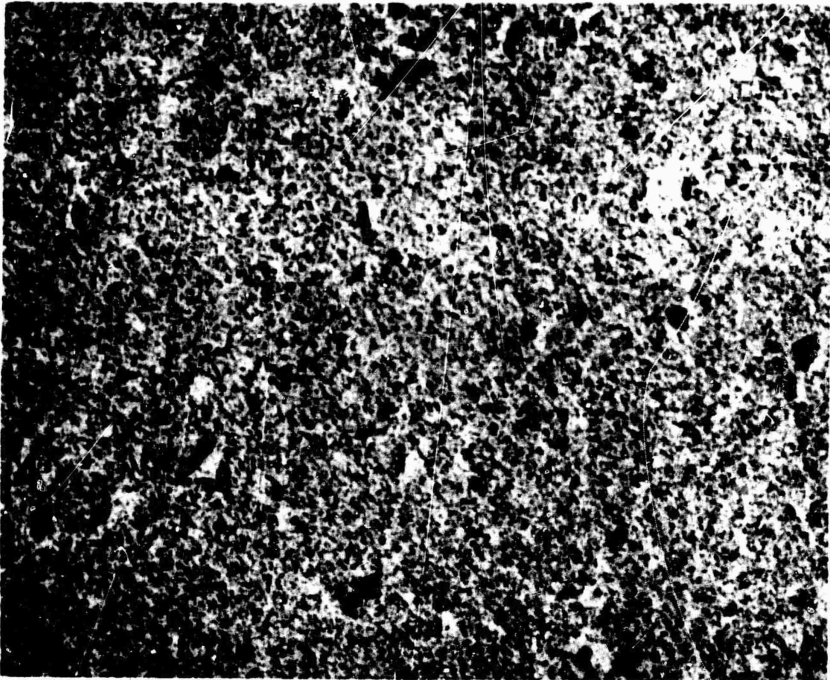
BILLET # 2
(53 X)



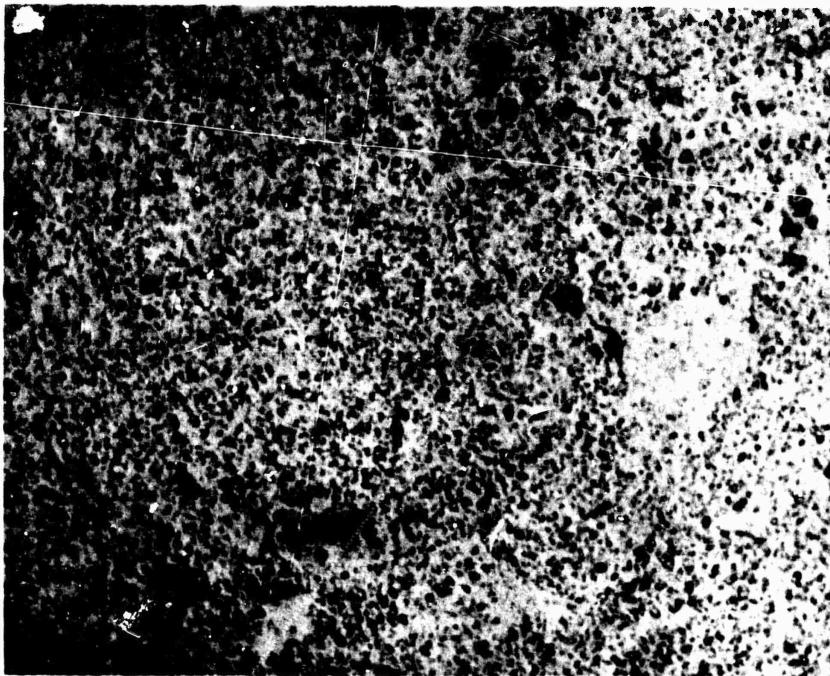
BILLET # 2
(212 X)

Figure 6

53X and 212X ENLARGEMENTS OF GRAIN STRUCTURE OF SPECIAL AXF-9Q BILLETS FABRICATED FOR THIS PROGRAM. PHOTOS ARE FROM HIGH ATTENUATION ZONES SHOWN IN FIGURES 4 AND 5.



BILLET # 3
(53 X)



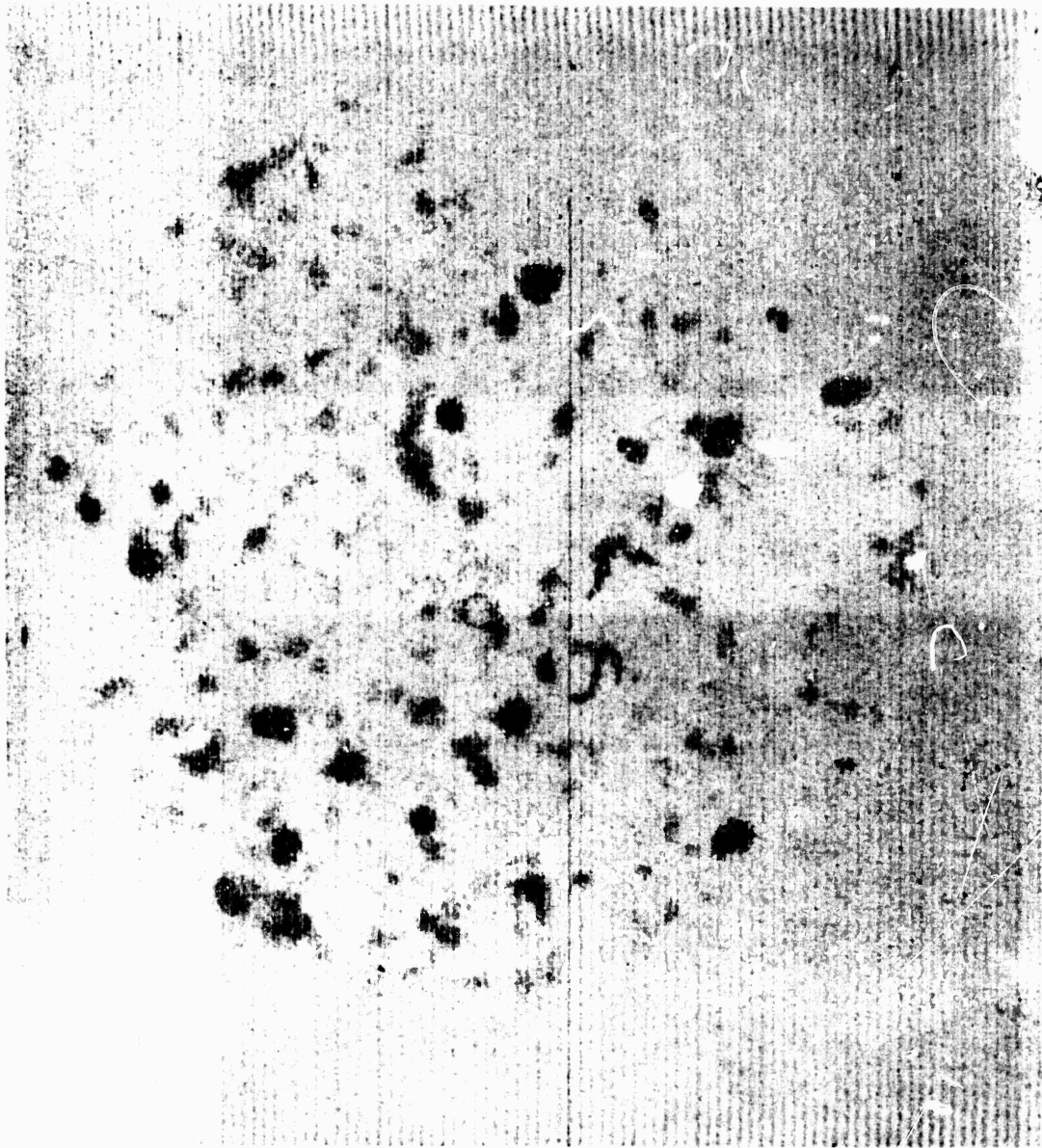
BILLET # 3
(212 X)

Figure 6

53X and 212X ENLARGEMENTS OF GRAIN STRUCTURE OF SPECIAL AXF-9Q BILLETS FABRICATED FOR THIS PROGRAM. PHOTOS ARE FROM HIGH ATTENUATION ZONES SHOWN IN FIGURES 4 AND 5.

Figure 7

SPURIOUS SIGNALS FROM IMPROPERLY TUNED IMMERSCOPE



Sample # 2

$\alpha = 2.25$ Mhz

Gain = 1.15

Sensitivity 4.85

DISCUSSION OF EXPERIMENTAL STUDIES

ULTRASONIC STUDIES

I. Evaluation of Basic Ultrasonic Test Parameters

a. Generator

Because it was intended to utilize a conventional ultrasonic generator as the basis for our many studies it was decided as an adjunct to these studies to evaluate the effect of the unit itself on the results observed. The generator used was a model 424A Immerscope with an attached Automation Industries (AI) Low Frequency Adaptor. Both units were over ten years old but had been successfully utilized for a variety of ultrasonic inspection problems in our production NDT area since they were acquired. Both units have the advantage of lending themselves to a variety of advanced applications. They are physically large so that access to the various signal processing stages is readily accomplished. Also, the Immerscope has external jacks for triggering pulses, both early and delay synchronization, external gating and a flaw signal from the built-in alarm circuit. The basic system is reasonably similar in operation to most of the ultrasonic generators in use today and a few words on this subject are in order. The transducer is shock excited by a repetitive high voltage pulse (~ 1200 V, rep. rate $\sim 20^{\circ}$ sec, pulse length $\sim .04$ sec). There is no pulse length or pulse tuning control on this unit. The rep. rate is adjustable but the control is inside the chassis. This mode of excitation coupled with the damped construction of most of today's transducers causes the transducer used to ring at its natural frequency (such as $2\ 1/4$ MHz) for about 5 to 7 cycles/pulse. The returning signals after being recovered back to electrical signals by the transducer are amplified through a two stage tuned RF amplifier, then modulated with a 60 MHz CW signal. This composite signal passes through an untuned 5 stage IF amplifier after which the envelope of original RF signal is detected and displayed very much like in a radio or TV set.

At the time the unit was built, only quartz and lithium transducers were widely used and separate impedance matching circuits were built into the Immerscope for these types. To account for individual differences, a "balancing pot" was also built in for final tuning. The LFA is basically similar in operation. It is triggered by the Immerscope and uses the same video display system. The major differences are a higher pulse voltage (~ 1700 V), somewhat longer pulse length, and the use of an untuned RF amplifier and tuned IF amplifier. It appears to have been balanced only for silica transducers. These two units cover a frequency range of .2 to 25 MHz.

Prior to and even after their acquisition by the NDT development laboratory the units were routinely used for the inspection of heat shields and other ultrasonic inspections but when they applied to these studies problems arose. It was quickly observed that when used on our AXF-9Q test blocks considerably (~ 5 times) more gain was required to achieve a clear signal from the artificial defects than that which had been required to just achieve a 100% full scale back echo. In achieving this level of gain it was noted that the baseline noise also increased greatly to the point where making reliable interpretations of the results was compromised. (Fig. 7) Since this was highly contrary to all our expectations for this material, a closer look at the signal source was taken. A check of the RF tuned amplifier with a sweep generator showed that normal aging had changed its characteristics and that retuning it significantly improved its response characteristics. Similarly aging components in the IF strip had degraded its capabilities insofar as gain was concerned. What appeared initially to be relatively minor baseline jitter was due to a defective capacitor in the HV

power supply which was putting out transients that were being picked up by the display circuitry at the higher gain levels needed. Lastly, the impedance mismatch between the unit and the ceramic transducers now used was definitely found to be causing small signal errors which were also being picked up and displayed. (Fig. 8) The retuning corrected much of this latter problem but the use of impedance matching connectors in the external cabling was finally necessary to reduce it to a tolerable level. When these problems were corrected much more reliable test results were obtained.

The point is made that the unit was doing a creditable job on other less refractory materials and we are sure so are most of the other units used in industry for graphite studies. However, unless care is taken to assure that the total ultrasonic system is matched and in the best possible operating condition it is possible to be in deep trouble with a material like graphite where the maximum system capabilities are required. This point cannot be overemphasized. Discussions with Mr. Henry Chaskilis (10) of the Naval Research Laboratory have indicated that no two of the commercially available ultrasonic systems in use today are identical in all their operating principles. There are enough differences in the modes of transducer excitation and amplifier characteristics to introduce considerable differences in the output display even if all external parameters (such as transducer used, geometric settings, etc.) are identical. Consequently, it is not possible to give more than general information as to how a conventional test should be set up and run. Procedures for checking and maintaining the basic capabilities of pulse echo systems are available and described in ASTM E317-67T and it is strongly recommended that these be implemented by all groups requiring the best capabilities from their ultrasonic equipment. In addition, it is also recommended that more serious consideration be given to requiring that equipment vendors provide basic information as to equipment electrical and mechanical characteristics so that a more meaningful approach to defining ultrasonic test parameters may be taken.

b. Transducers

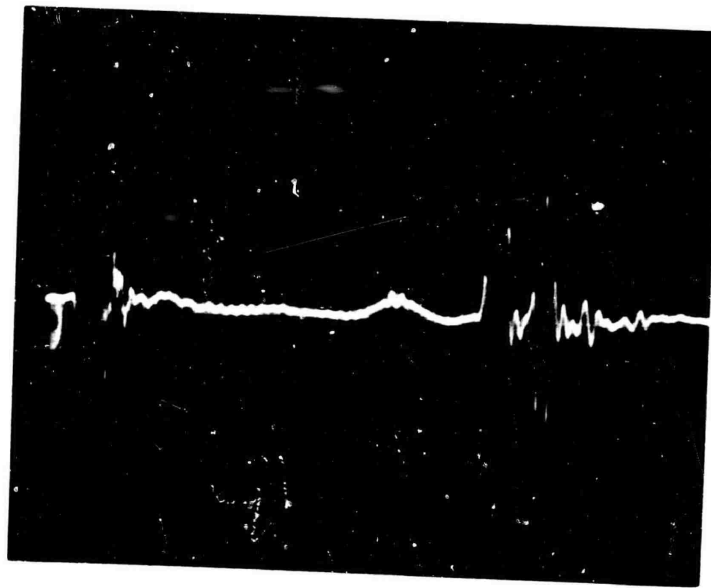
A second area of concern was with the transducers used for these studies. These were Automation Industries AA 3/4" diameter and BB 1/2" diameter ceramic units. Data published by AI (11) indicated nominal focal lengths of 5.2" and 3.7" respectively for these transducers and the earliest investigations were made on the assumption that these numbers applied to the 1 and 2 1/4 MHz transducers used. Subsequent checking on this point revealed that the data published only applied to transducers of 5 MHz and up in the configurations we were using and that in our case the true focal length could be as much as 1/3 to 1/2 of the "nominal" data quoted.

Secondly, it was found that the focal length was not exactly constant. It was learned from AI that for ceramic transducer elements the optimum pulsing voltage is about 35 V/mil of thickness which worked out to be far below the immerscope and LFA outputs. To reduce the voltage to something approaching the optimum value external attenuators were attached to the output jack. While this was being done checks on the response of the transducer were being made by noting the water path distance required to achieve a maximum indication from a .090" diameter flat bottomed hole in a 1" thick ATJ-S test block. As the pulse voltage changed so did the water path distance (Table 3) so that again care must be taken in duplicating and calibrating all test conditions if best results are to be achieved.

As noted above this includes careful attention to such details as properly terminated coaxial cables in the external system.

Figure 8

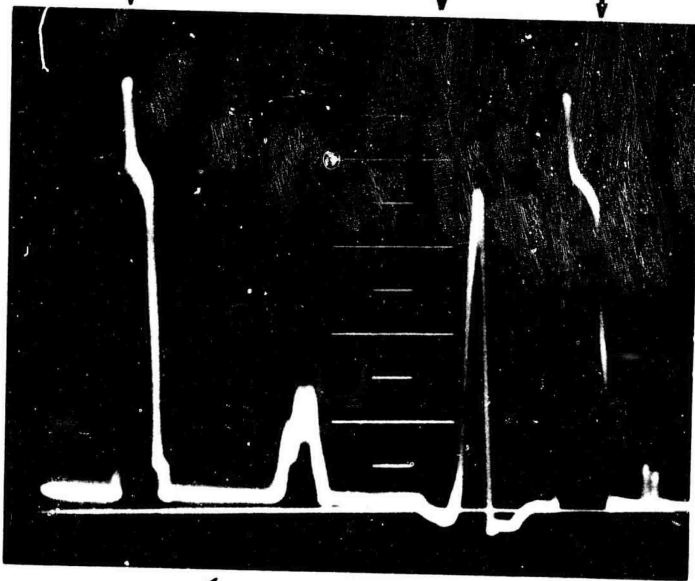
COMPARISON OF IMMERSCOPE AND TEKTRONIX 535A
DISPLAYS OF SAME SIGNAL



↑
Front
Surface
↓

↑
Defect
Echo
↓

↑
Back
Surface
↓



↗
Spurious signal caused by impedance mismatch in Immerscope

c. Recording System

As with most ultrasonic recording systems, the unit used for this work was an "off-on" system writing only when the signal in the flaw alarm gate exceeded some present threshold and sensitivity settings. This type of system allows the user to tune out baseline noise but suffers from the disadvantage of not presenting much more than a binary yes-no type of signal. The magnitude of the signal displayed is of no concern once it exceeds the threshold so that the ability to interpret the relative significance of different indications is definitely impaired. A number of different answers exist to this problem some of which are presently incorporated into advanced ultrasonic systems now available. However these systems are often highly specific to the basic ultrasonic generators used. To answer this need we are working on a low cost system capable of being used as an add-on to any ultrasonic generator which can produce a gated output signal.

Lastly as with most recording systems used in ultrasonics the control potentiometers ("pots") used were single turn units having broad settings and some backlash. This created considerable difficulty in first precisely defining the particular threshold and sensitivity settings used and then reproducing them later on if any changes had been made. To correct this situation, these along with the similar gate control pots in the Immerscope were changed to precision ten turn units having no backlash.

The remarks in the preceding sections are intended not to show that ultrasonic inspection of graphite is impossible (although as we shall see later on there are definite limitations as to what can be done) but rather the inspection must be carefully setup and controlled. Without such care the probability for error is much higher than need be the case. It is repeated that procedures for exercising such controls are available and fairly easily implemented. The improved results, of course, accrue to all of the ultrasonic inspection performed with the units so maintained.

TABLE 3

VARIATION OF FOCAL DISTANCE WITH DRIVING VOLTAGE

PULSE VOLTAGE	Transducer to surface distance to achieve maximum defect signal amplitude from a fixed .020" dia flat bottomed hole in AXF-9Q graphite.
210	1"
190	7/8"
165	13/16"
150	1/2"

NOTE: 2 1/4 MHz AI Transducer, type 57A3618, long focus

II. FOCAL PLANE STUDIES

a. Theory

In this technique, the theory states that maximum sensitivity to small conditions is encountered in ultrasonic C scan mapping if the recording gate is placed along the scope base line at the position corresponding in the material being inspected to the location of the focal plane of the transducer. (2) By varying the water path of the sound beam it is possible to position the depth of the focal plane once the ratio of the acoustic velocities of water and the test material are known. For ATJ-S graphite a typical value of acoustic velocity is approximately 2.03 mm/u sec. while for water a value of 1.49 mm/ u sec. is usually quoted thus giving a velocity ratio 1.36.

Using the formula:

$$FD_{(H_2O)} = (MR \times MD) + WP$$

where FD = focal distance (total)
MR = material/water velocity ratio (\approx 1.36 for ATJ-S graphite)
MD = material distance
WP = water path

the water path distance to any plane in the material could be calculated and set up. (11) Changing the water path would of course change the depth of the focal plane and thus the zone of maximum sensitivity in the material.

Initially, for these studies a 4" x 4" x 1" test piece of "nominal" ATJ-S graphite was used. This block had a grid of 1/4" deep flat bottomed holes in the range of .090" to .010" diameters drilled up from the bottom (Figure 9).

Subsequently, it was found that the "dead zone" previously noted for this material ran through or was adjacent to two of the holes. Prior to testing, all holes were covered with "Scotch" tape, and the entire block waterproofed with two coats of Turco 4497 strippable sealing agent. To augment this program it was planned to test the block as follows:

The gain control was set at the minimum value necessary to maximize the reflection from the .090" dia. defect. Using the base line markers of the Immerscope as a guide, the gate was positioned initially at the plane of the artificial defects (\approx 3/4" through the block). To discriminate against noise a narrow (5 u sec) gate and a 20% recording threshold were used. Thus any background hash should fall either outside the gate or below the threshold acceptance level of the recording amplifier used. Also no signal less than 20% of full amplitude in the gate would be recorded. This sequence started with the focal plane at or slightly above the front surface of the block. The transducer was then lowered in 1/4" increments toward the test block until we were reasonably certain that the focal plane had been advanced all the way through the block. When the AXF-9Q material was received similar studies were made. Because of the success in displaying the larger defects in the ATJ-S block (see below) the maximum sized artificial defect in the test block was only .050" diameter.

Test runs were made at both 1 and 2 1/4 MHz in the ATJ-S block and at 2 1/4 MHz for the AXF-9Q test blocks.

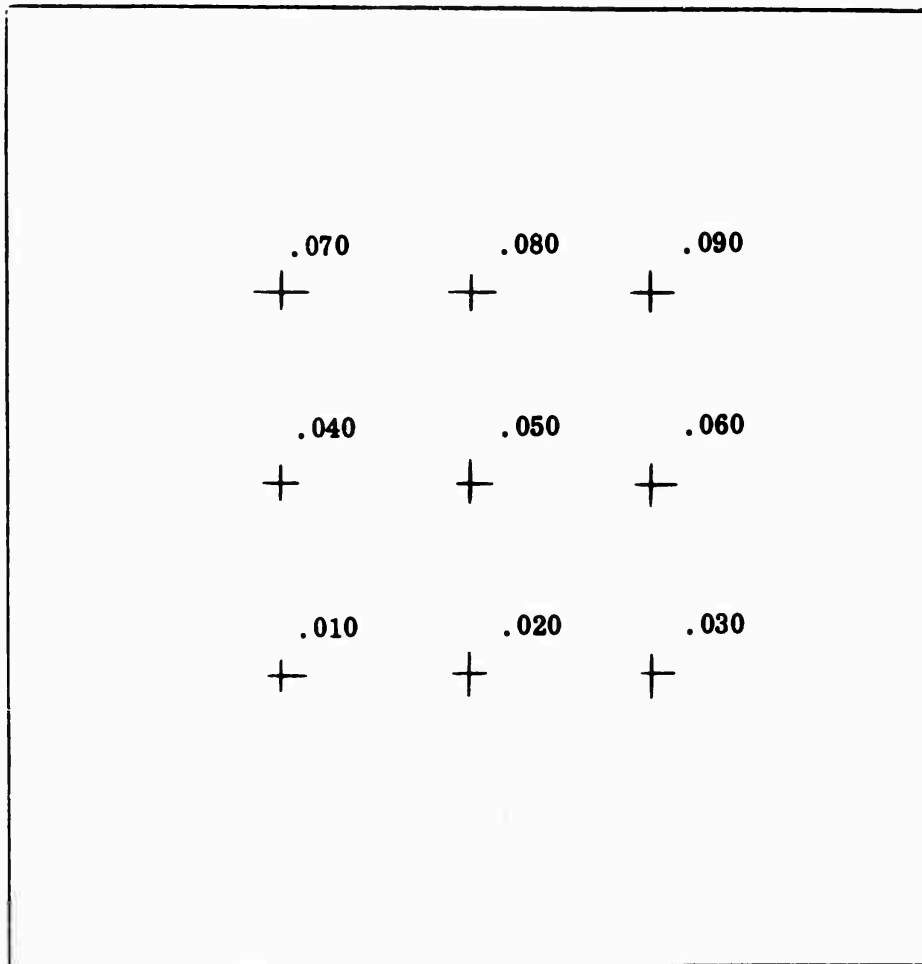


Figure 9

ATJ-S TEST BLOCK

Hole diameter shown on drawing
Block thickness - 1"
Hole depth - 1/4" up from bottom

b. Results

For the ATJ-S sample tested, better results were obtained at 1 MHz than at 2 1/4 MHz. This was not expected and is probably related to the fact that the shorter wavelengths of the 2 1/4 MHz beam ($\lambda = .036''$) are beginning to approach the size of whatever is causing the noise in the block so that scatter phenomena became more important here than at 1 MHz ($\lambda = .080''$) (Fig. 10) It was found that these scatterers tended to be extremely ephemeral in nature as compared to good defect signals (Fig. 7, 5) However, because the amplitudes of some of these signals are quite high interpretation of the A scan scope image is virtually impossible; it is only by C scan mapping in conjunction with good standards that these conditions can even begin to be interpreted. It was noted that the back half of the scope baseline was somewhat freer of noise than the front half. (Fig. 11) This may be due to some sort of resonance effect near the top of the material. That it is not due to differences in the material itself was shown by the fact that the same effect was noted when the test block was turned over and retested. This condition, whatever its cause, was unique to the ATJ-S since a similar problem was not observed with AXF-9Q. For both materials, when the traces at different focal plane settings were compared, noticeable similarities and differences appeared. The larger defects in the blocks appeared at almost any setting of the gain control and focal plane. It mattered little whether the plane was above, at or below the defect. However, in regard to the smaller holes it was only when the focal plane approached or passed the plane of the hole that they came into view. Thus in Figure 12 the .050" hole of the ATJ-S test block did not come into view until the calculated focal plane approached it. A previous x-ray inspection of the block had shown that this hole along with the missing smaller ones in the grid were somewhat cocked and that their effective reflecting surfaces were less than their apparent ones. Once the focal plane came close to the .050" hole no trouble was encountered in detecting it.

It will be noted that the maps produced for the ATJ-S blocks show considerable magnification of the defects. These tests were made before the definitive information in regard to the true focal length was known and it was initially assumed that this was a function of the small increments ($\sim .030''$) used on the scanning unit. With the correct focal length data it is easily deduced that this is strictly a function of being somewhat out in the far field of the transducer beam. When the AXF-9Q blocks were tested, the correct focal plane distances were known and much less magnification was observed. (Figure 13).

As noted, the principal studies performed to date have been with 1" thick standard defect blocks. Some tests made with a 3" thick ATJ-S standard defect block showed analysis of these results to be more complex than with the 1" block. Since the original intention was to work with 1" maximum sections, further work with 3" sections has been dropped. (Figure 14).

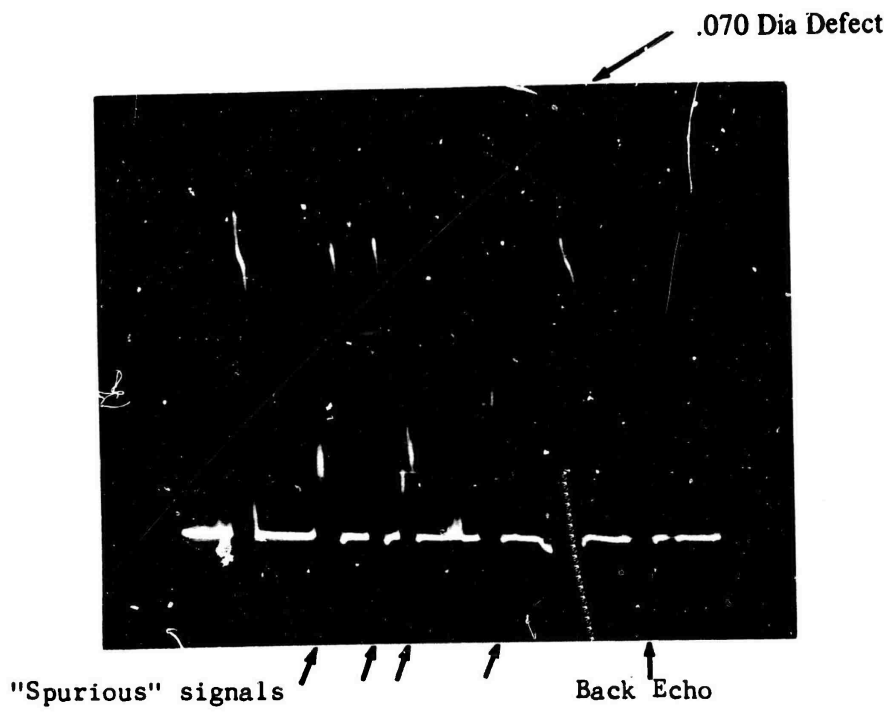
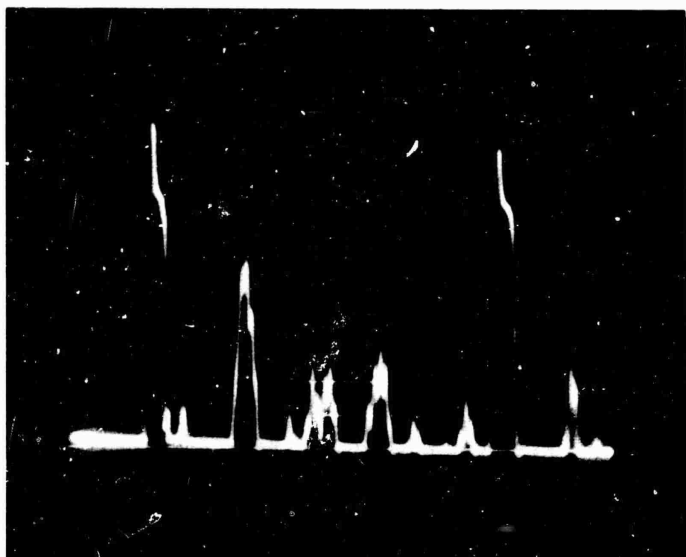
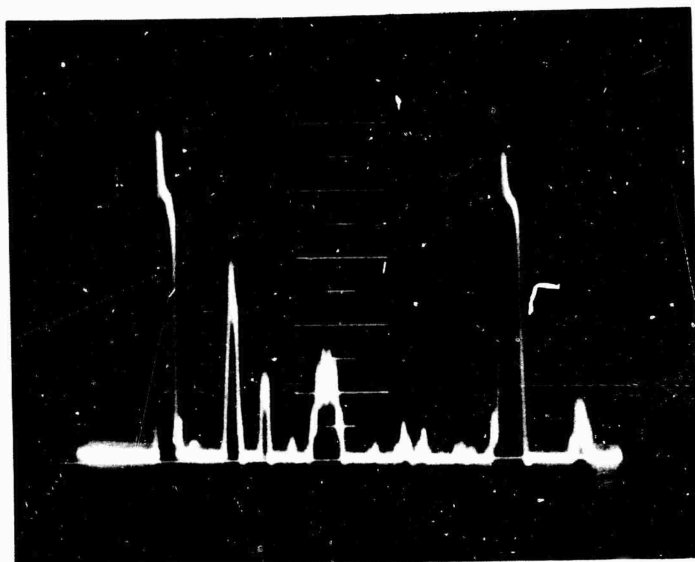


Figure 10
Scatter at 2 1/4 MHz in ATJ-S graphite



a

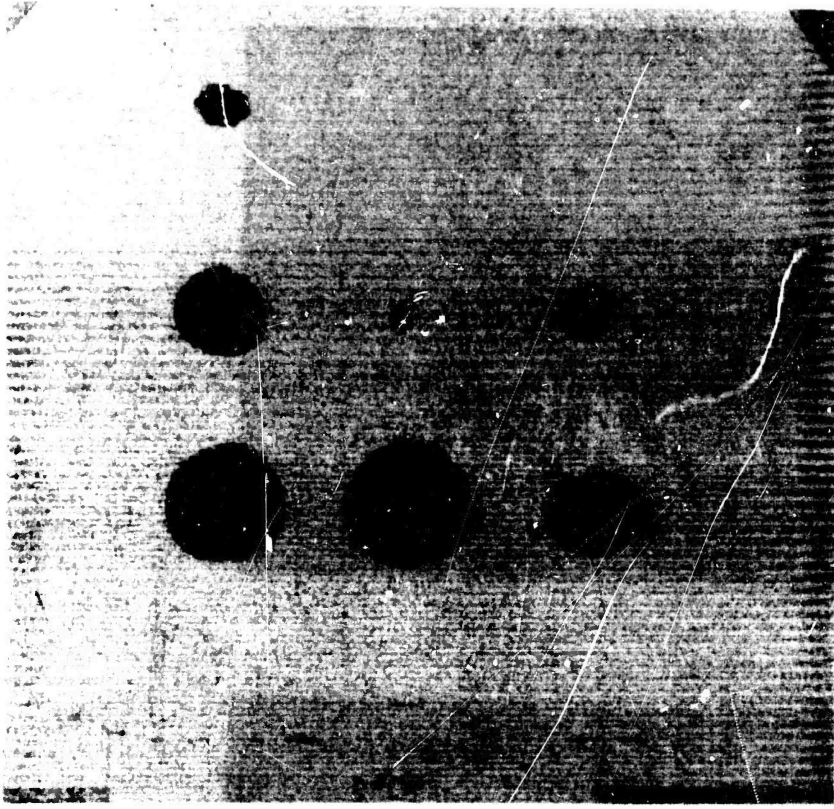


b

- a. Front-to-back
- b. Back-to-front

Figure 11. "Resonance Condition" in ATJ-S Graphite

B



A

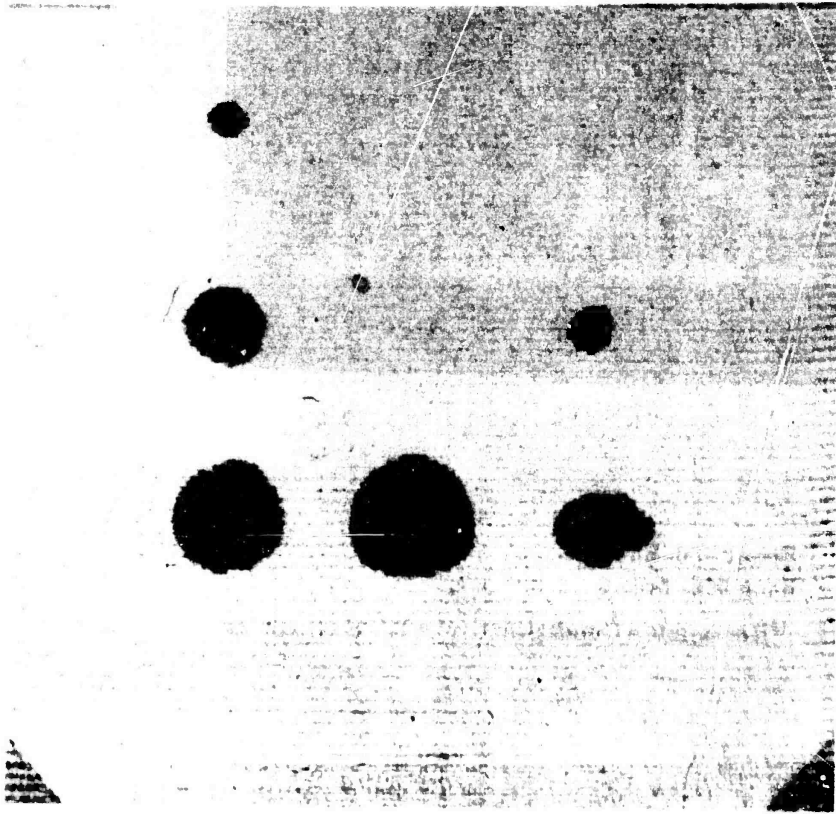
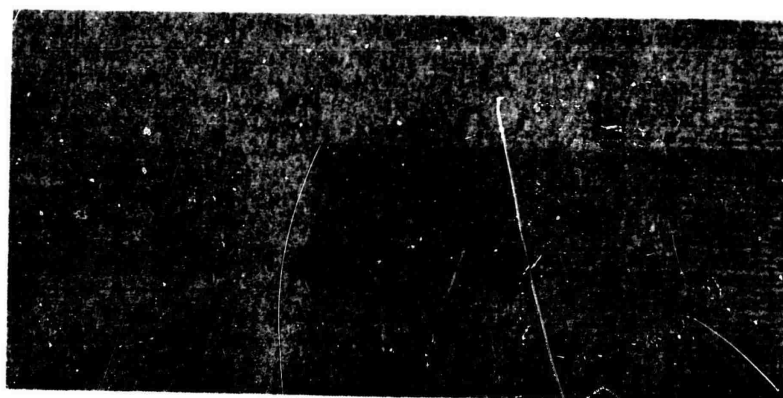


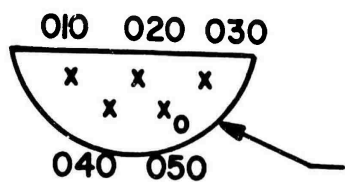
Figure 12. 1 mc recordings of ATJ-S block shown in Figure 9. Transducer height 4 1/2" and 4 3/4" respectively. Note appearance of .050 hole. All recording and inspection parameters in Figures A and B are the same.

Figure 13



2 1/4 MHz scan of AXF-9Q Billet #1

Focal length 1 1/4" to top of block.
Defect plane is 3/4" below surface



Possible natural
condition in graphite

Note lower degree of magnification as compared to Figure 11 due to more precise determination of focal length.

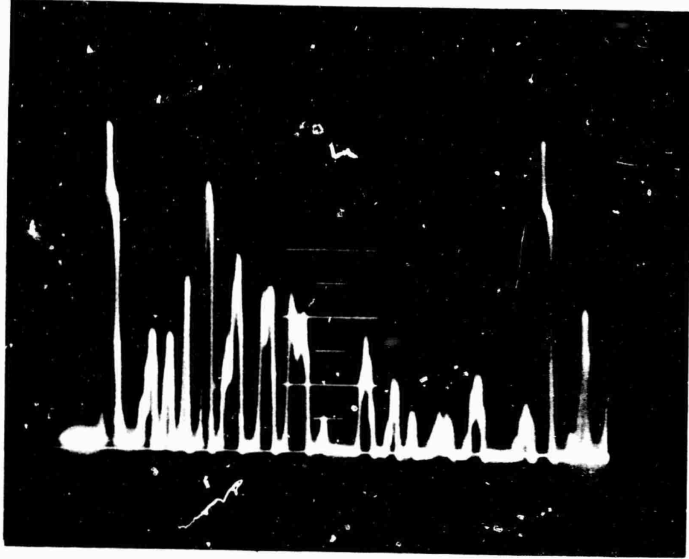


Figure 14

ATJ-S Graphite Signal at 2.25 MHz
through 3" sample.

c. Evaluation of Results

Once the generator modifications were completed and focal plane confusion cleared up it was possible to draw some final conclusion as to the efficacy of this approach. It has already been stated that the system once properly tuned did tend to produce clearer, less noisy and more easily interpretable A scan and C scan outputs.

When these changes were done we were able to resolve and map flat bottomed holes between .020" and .030" diameter, 3/4 of an inch deep in a 1" thick ATJ-S and approximately .010" diameter in a similarly configured AXF-9Q block. The "resonance" condition in the ATJ-S effectively limited mapping to the back half of the test block but AXF-9Q would be inspectable much closer to the top surface. (Fig.15) However at no time were we ever completely free of "spurious" A scan signals, some of considerable amplitude, either in the focal plane or close to it so that no definitive evaluation of a pure A scan signal as it is displayed on the CR tube of an ultrasonic generator seems possible. Furthermore, it must be remembered that a flat bottomed hole is really an ideal defect for ultrasonic testing. Recently, on another project involving ultrasonic inspection, the worst case relationship between the signals from a spherical void and flat bottomed hole in a Hitt block was evaluated and computed. Under conditions of identical echo amplitude the sphere could be considerably larger in diameter than the flat bottomed hole. (13) This exercise tends to throw into some doubt the meaning of any ultrasonic test based on Hitt block standards. Consequently, it is not possible to make more than generalizations as to the degree of actual improvement accomplished. However, it is felt that conventional ultrasonic techniques can not be made to perform much better than was observed in these tests and consequently no further work is recommended in this area of NDT interrogation.

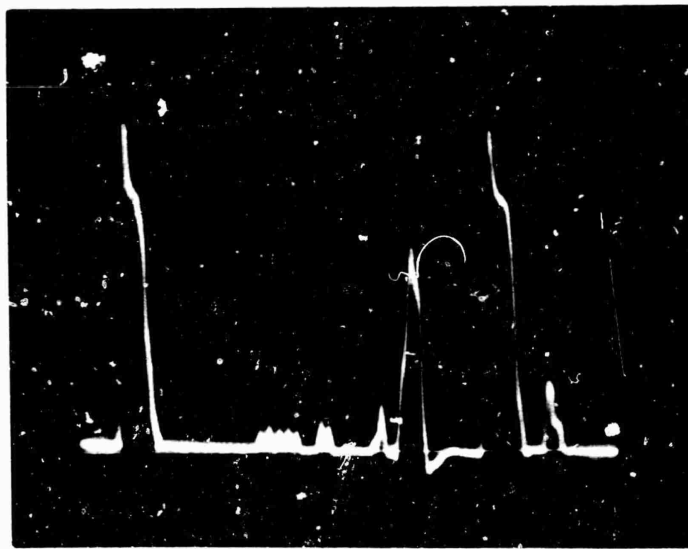


Figure 15

AXF-9Q Graphite

Immerscope Photograph showing .020" defect at 2.25 MHZ.

Note relative absence of background noise along baseline.

III. FREQUENCY DOMAIN ANALYSIS

a. Theory

There are several methods for describing electrical or mechanical vibration phenomena. If the vibration is periodic all the information for a complete description is contained in one period of the signal. However, if it is nonperiodic, an infinitely long record of the signal is theoretically necessary for a complete description. This is of course, an impossible requirement in practice. Furthermore, if the time record becomes too long it also becomes a very inconvenient signal description and other methods are commonly used.

One of the best known methods is the use of frequency analysis techniques which describe the phenomenon, not in the time domain, but in the frequency domain. The result of a frequency analysis is a frequency spectrum which may be presented in various ways. Two of the most commonly used methods are:

1. Amplitude level vs. frequency
2. Power spectral density.

The former method is merely a Fourier analysis of a selected portion of the signal being considered. The power spectral density may be defined:

$$W(f) = \lim_{B \rightarrow 0} \lim_{T \rightarrow \infty} \frac{1}{BT} \int_0^T X_B^2(f, t) dt$$

and describes that part of the average power of the signal time function $X(t)$ which is contained in an infinitely narrow frequency band, B , centered at the frequency, f , and averaged over an infinitely long time, T . In practice both B and T are finite and the integration is done with a computer. (14)

In the studies performed in this program both types of data will be generated and analyzed.

b. Preliminary Experimental Studies

The first efforts along this line were set up, at the suggestion of Carl Hastings at AVCO, with Mr. Otto Gericke at the Army Materials and Mechanics Research Center (AMMRC). Mr. Gericke has written extensively on this subject and is the foremost authority on it, although his efforts appear to be primarily limited to amplitude/frequency presentations. Mr. Gericke's facility is also quite sophisticated. Accordingly, four pieces of ATJ-S graphite, each $2\frac{1}{2}$ " square by 1" thick cut from the same 8" diameter slice were prepared. Each piece was machined with the front and back surface flat and parallel and polished to remove machining marks. These pieces were also x-ray and ultrasonically inspected to assure no natural gross conditions existed. They were then gridded on $\frac{1}{2}$ " squares and the ultrasonic velocity measured for each square. As previously noted, these measurements showed a typical "dry core" condition existed with a sharp difference in velocity of about .006 u sec/inch ($\sim 8\%$) between the inner and outer zones and

an acoustically dead band at the interface. Lastly, in three of the blocks, two small flat bottom holes were drilled $\frac{1}{2}$ " and $\frac{1}{4}$ " respectively up from the bottom of each hole (Figure 16). These were plugged and all four blocks given two coats of Turco 4497. At the conclusions of these preliminaries the parts and all pertinent data were sent to AMMRC.

Mr. Garricke's tests were done using the techniques and facilities described in his reports (References 4, 15). The transducer was bonded to the top of the block and pulsed, the return signal was gated out into a spectrum analyzer the results of which were displayed on a storage oscilloscope. By so doing, it was possible to display several spectra at once for comparative studies. Initially spectra were made at $2\frac{1}{2}$ MHz using a $\frac{3}{4}$ " transducer bonded to the surface of the block and these showed that in nearly every case a clear difference was shown between the high and low velocity areas (Figure 17). As can be seen in the lower velocity zone there is a marked reduction in the higher frequency components. These data correspond closely to those reported by Serabian on related studies in ATJ material⁽¹⁶⁾ and an apparent shift in the peak frequency amplitude. However, when spectra were made over one of the drilled holes, a spectrum intermediate between the gross background spectra in the two zonal areas was observed. Additional tests subsequently made at 1 MHz using an unfocused immersed $\frac{3}{4}$ " transducer showed similar results. Since these tests, work has been underway to adapt the RESD system to the purpose since it was felt that by adapting this analytical technique to the Focal Plane and Delta Studies being performed, additional useful information could be acquired fairly easily. To this end, the Immerscope itself was modified so that signals could be acquired from the grid of the first RF amplifier (just prior to entering the tuning circuit), the plate of the last IF stage (before detection for video display), the plate of the video output tube and the pulser trigger. By so doing, it is possible to display any part of the signal for external analysis. This modification is not quite complete. It has been found that "main bang" even when severely attenuated tends to saturate the external scope amplifiers and introduce severe "jitter" (Figure 18) into the display. This jitter severely degrades the displays for subsequent analyses. This will be corrected by either using a diode clipper to chop off the peak of the main bang signal received, thus reducing it to the level of the rest of the signal or a gating circuit to prevent the main bang from ever getting into the scope. This last approach is used at AMMRC but the clipper circuit is easier to implement and will be used here.

Analysis is to be done in several ways. For the first part, the individual echoes and noise signals will be monitored with a spectrum analyzer plug-in. This will be done by isolating the signal of interest with the sweep delay feature of a Tektronix 535 scope, then jacking it off the vertical plates of the CR tube into a 1L10 spectrum analyzer plug-in of a Tektronix 555 dual beam scope for quick analysis.

Areas showing "interesting" responses will have the wave forms photographed for computer analysis by the RESD Data Processing Group. This group has developed techniques for making transforms of high speed transients from scope photographs. For our purposes they will provide the spectral density and power density functions of each signal. In addition, if needed, forward and inverse transfer functions can be provided. These latter are primarily useful for analyzing "black boxes" and express the output in terms of step or impulse inputs so that their utility for this work is open to some doubt, but the capability is there, if needed. Typical photographs of particular signals are shown in Figures 19, 20, and 21. These show the front and back reflections from the "sound" and more highly attenuating areas

Frequency Domain Analysis

Preliminary Velocity

Characterization of ATJ-S Test Blocks

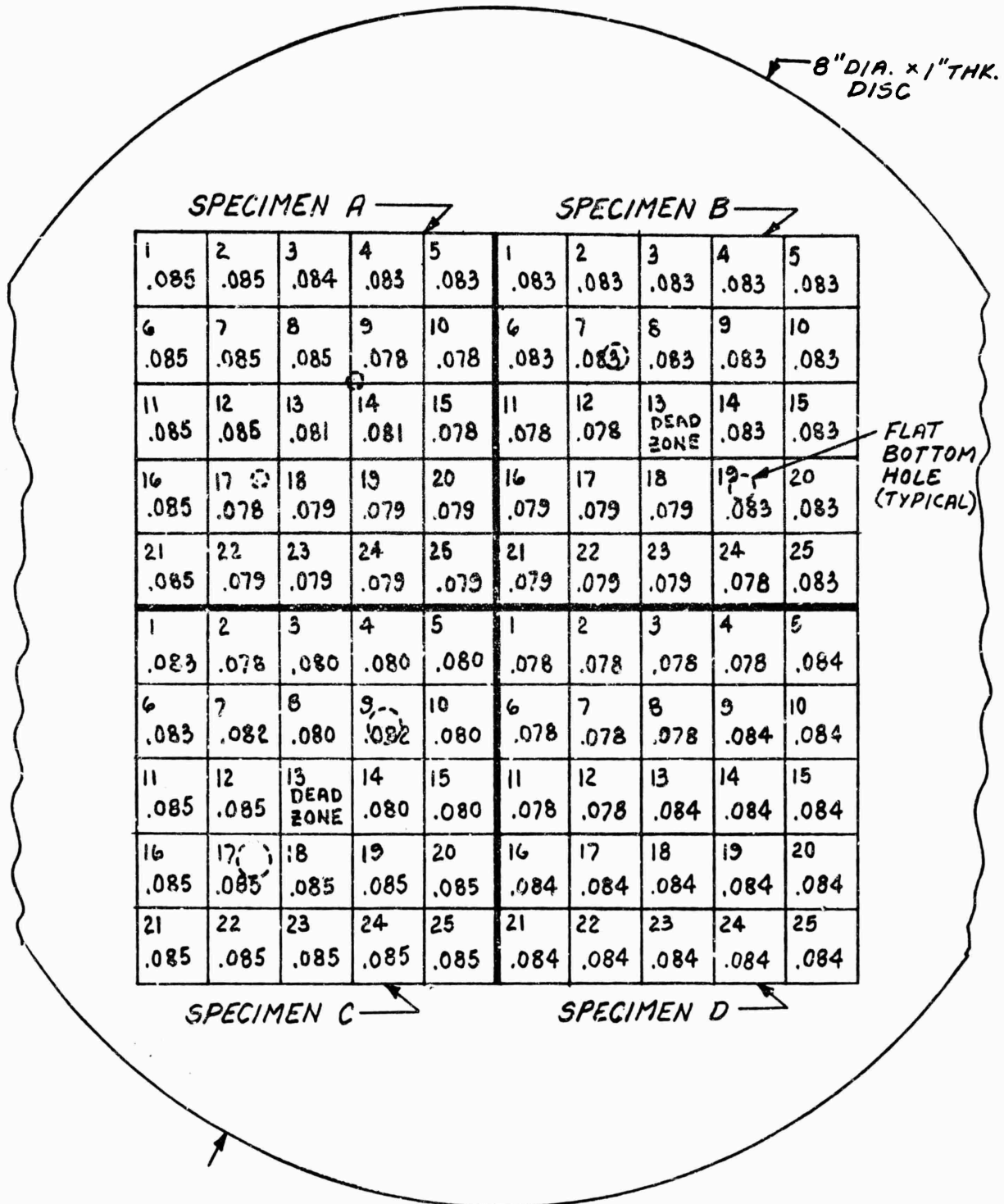


Figure 16

Showing Relation of Test Specimens

To Original Disc

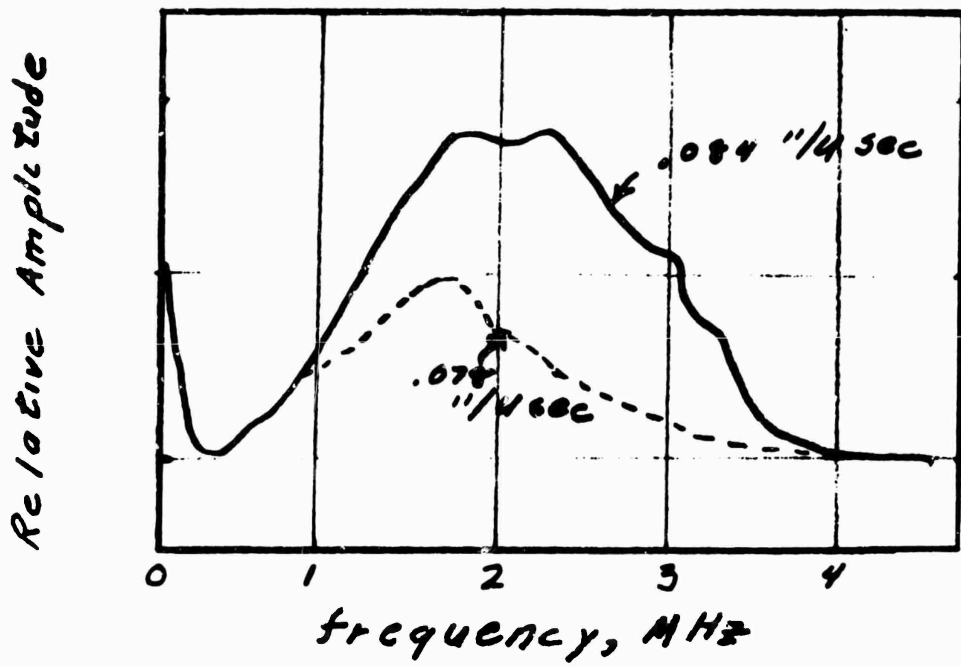


Figure 17

AMMRC STUDIES

Relative Distribution of Spectral Components

In $2\frac{1}{2}$ MC. Ultrasonic Signal From

ATJ-S Graphite

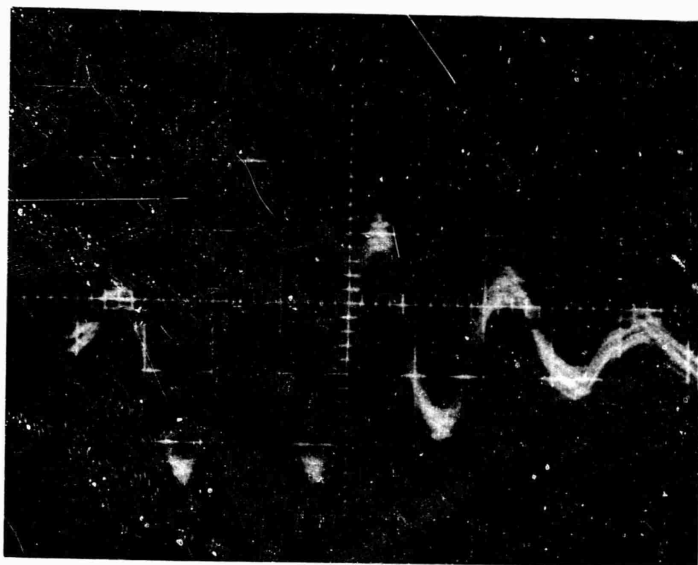


Figure 18

Jitter (Distortion) from .030" defect signal due
to Oscilloscope ample saturation caused by 300 Volt
'main bang" at $2\frac{1}{4}$ MHz.

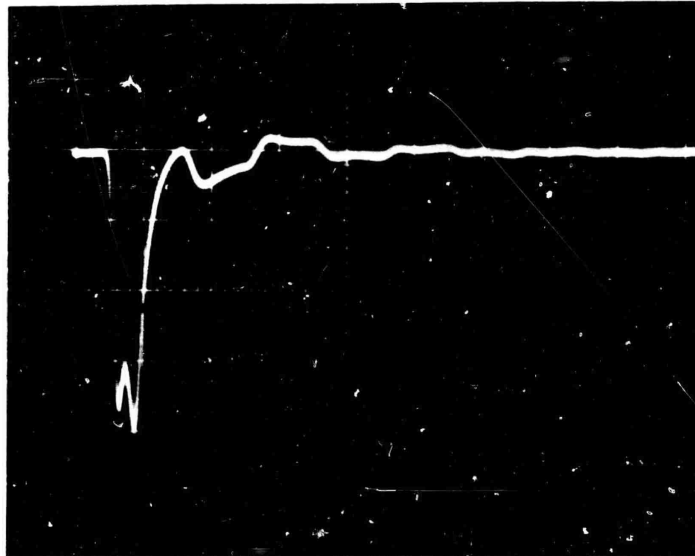
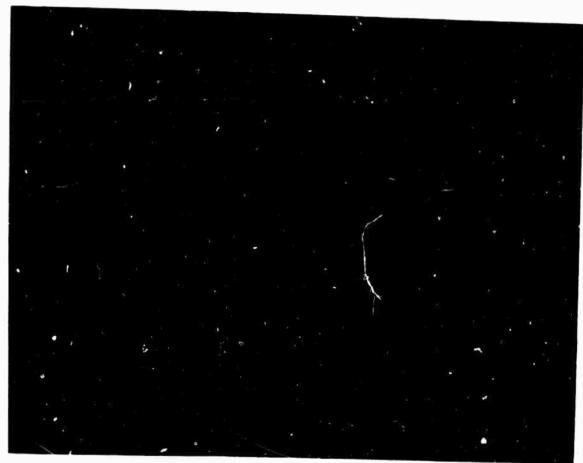


Figure 19

"MAIN BANG" FROM $2\frac{1}{2}$ MHZ TRANSDUCER (THIS IS COMMON TO ALL SUBSEQUENT SERIES OF PHOTOGRAPHS)



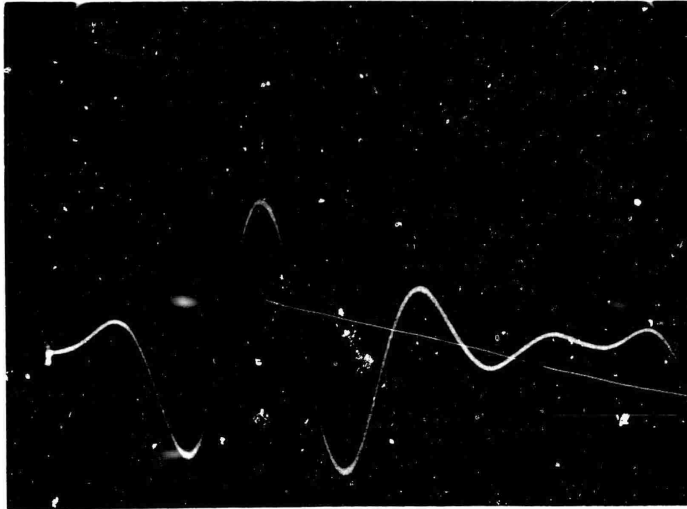
"MORE ATTENUATING AREA"



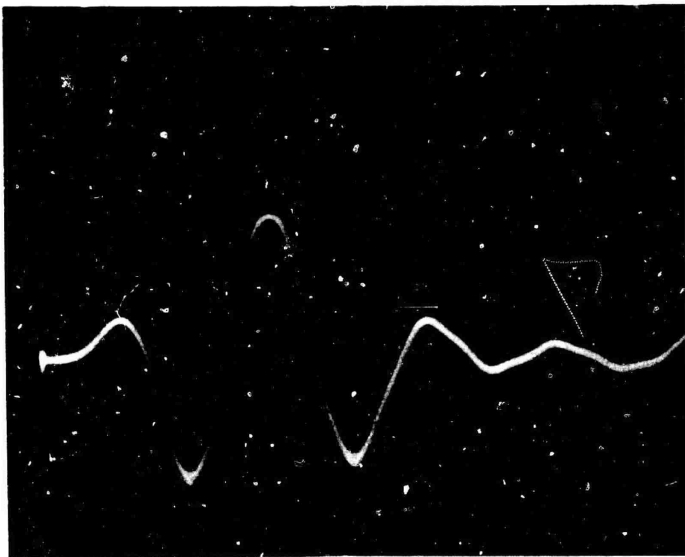
"LESS ATTENUATING AREA"

Figure 20A

FRONT SURFACE ECHOES FROM AXF-9Q BILLET # 2 MATERIAL



LESS ATTENUATING AREA

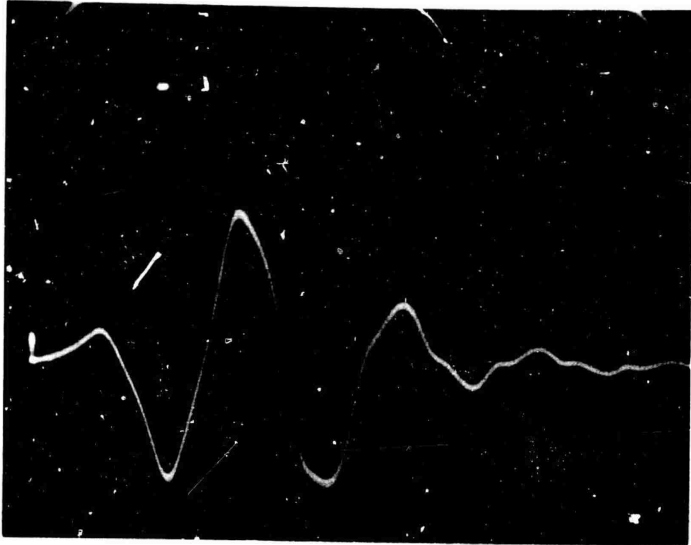


MORE ATTENUATING AREA

NOT REPRODUCIBLE

Figure 20B

BACK SURFACE ECHOES FROM AXF-9Q BILLET # 2



FRONT SURFACE ECHO

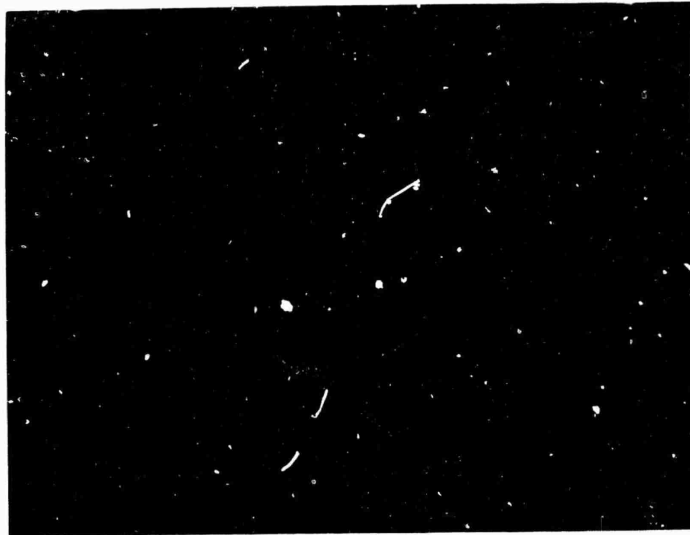


BACK ECHO

NOT REPRODUCIBLE

Figure 21A

NOT REPRODUCIBLE



Echo from .080" Flat
Bottomed Hole 1/4" up
from Bottom of Block

Figure 21B

**ECHOES RECEIVED FROM ATJ-S STANDARD
DEFECT BLOCK**

Notice apparently large change in echo pattern as compared to
the front and back reflection patterns.

NOTE: In Figures 19, 20, and 21 all photos are made at 0.2 sec/mm
sweep speed and with the traces normalized at about 4 mm
peak to peak. All traces are made at 2 1/4 mc using a type
BB long focus transducer located 1 1/4" above the surface
of 1" test blocks.

of AXF-9Q Billet #2 and from the "old" ATJ-S standard defect block. Note that the front surface echoes look essentially identical in all cases (the phase inversion between the AXF-9Q and ATJ-S signals is due to the use of different plug-in amplifiers in the external scope and is not related to the properties of the surfaces themselves) but that the rear surface echoes are quite different. The AXF-9Q signal approaches a sine wave in appearance while the ATJ-S signal resembles a saw-tooth. This is undoubtedly related to the higher acoustic attenuation experienced with ATJ-S. Most interestingly however, was the reflection received from the flat bottomed 0.070" hole in the ATJ-S block. This photo shows a definite difference from any of the other reflections from that block and is unlike any other signal recorded in this series. Also note that the AXF-9Q rear surface echoes show relatively small apparent wave form difference from a "good" area and one which attenuated the back echo by about 50%. Photos similar to these will be sent to Data Processing Group for spectral analysis when the final modifications to the system are completed.

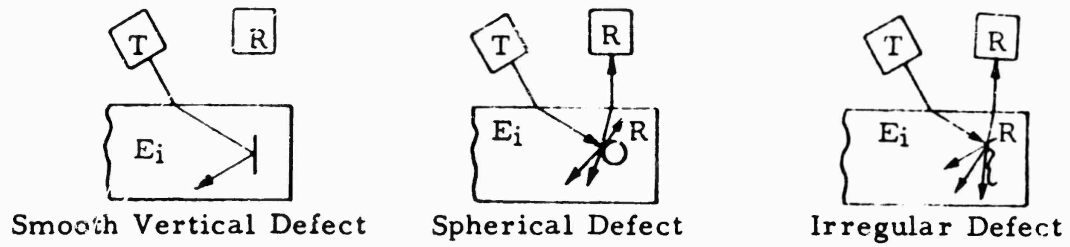
c. Evaluation of Results

The application of spectral analysis techniques to ultrasonic testing is not yet developed enough to make a definitive evaluation of the method. Such data as have been developed are very encouraging that a meaningful use of this approach can, in fact, be developed. It would appear to be especially useful in analyzing the unprocessed signals picked directly off the transducer before machine made alterations destroy the bases signals of interest. Examination of this trace shows generally a lower noise content than Immerscope A scan display, and that, interestingly enough, we get more echoes to evaluate. Signal decay in the Immerscope is much more rapid than in the Tektronicscope. Insofar as utility is concerned, discussions with Mr. Gerricke indicate that for conditions of the sizes we are seeking, the likelihood of receiving unique spectral signatures from different types of defects is small; yet the data do appear to indicate that different types of grosser conditions do produce different spectra. Consequently, it is planned to expedite the final modifications to the system for definitive evaluation of this approach to ultrasonic test interpretation.

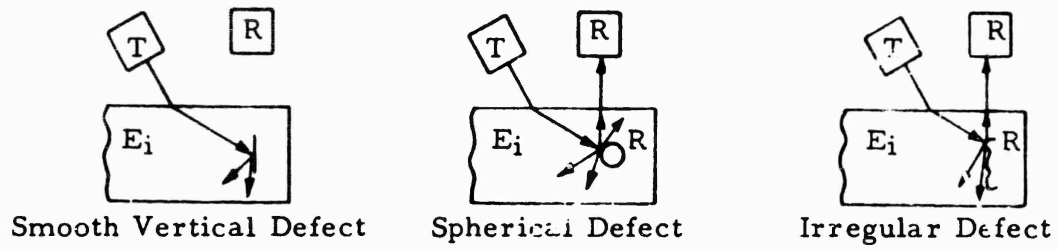
IV. DELTA SCANNING

a. Theory

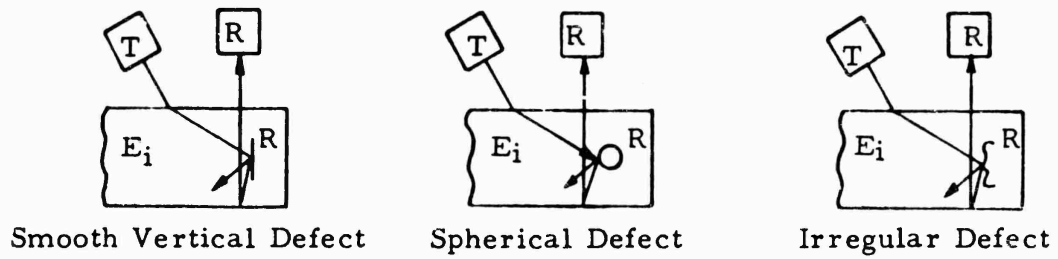
One major improvement in the ultrasonic inspection of welds has been the development of the delta inspection system. This approach to weld inspection offers a fundamentally different way of detecting flaws in that it detects not so much a reflection of the original signal but rather a completely different signal emanating from the defect. Basically, what is done is to irradiate the condition being sought at an angle rather than strength down as with conventional pulse echo ultrasonic testing. On making contact with the flaw several different things happen to the probing sound beam. These include scatter, reflection, mode conversion (longitudinal to shear wave) and, most significantly, resonant cavity reradiation (Figure 22). Many of these beam alterations lack the directional quality of the interrogating probe beam - that is components of the response may be detected at almost any angle relative to either the defect or probe beam. Thus they differ from the signals usually received in normal ultrasonic testing where the points where signal reflections may be picked up can be plotted fairly easily based on Snell's law and normal optical reflection principles. Consequently, if a transducer is placed in a position other than where reflections will normally occur, any signals observed by it can be considered to arise from defects within the material. (2) Figure 23 shows the test setup.



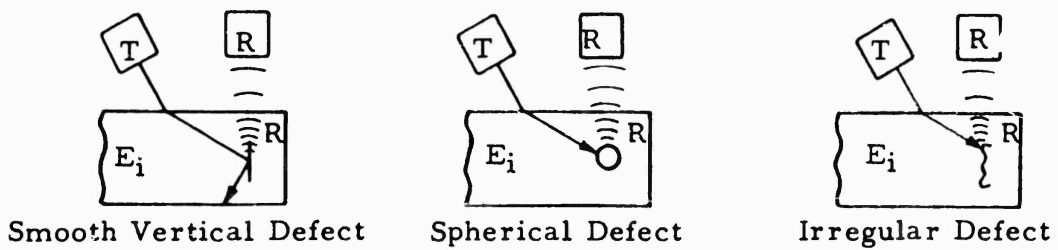
Reflected Energy



Mode Converted Energy (Direct)



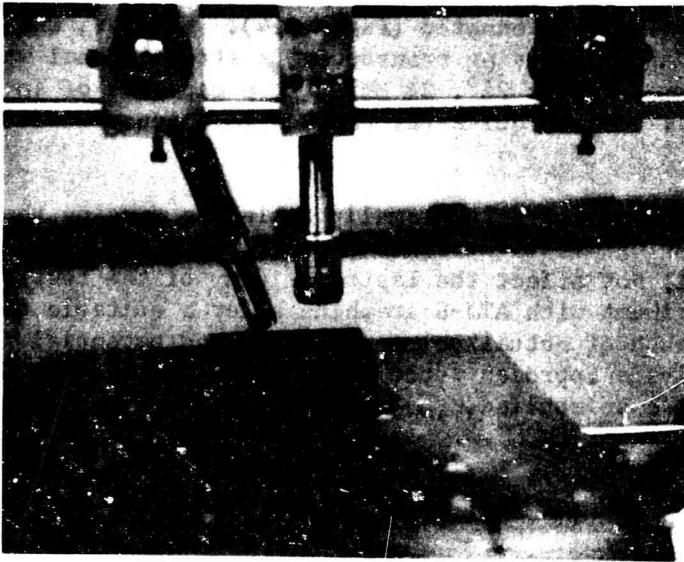
Mode Converted Energy (Indirect)



Reradiated Energy

Figure 22 Redirected Sound Energy

From DELTA Scan



NOT REPRODUCIBLE

Figure 23

CLOSE UP OF DELTA SCAN SET-UP

b. Preliminary Results

The Delta unit was acquired late in the year so extensive studies were not possible with it. In the first studies with a $\frac{1}{2}$ " dia. long focus 2½ MHz ceramic transducer a large quantity of sound was picked up by a 2½ MHz focussed 1" diameter transducer (similar to that used by Cross) from an AXF-9Q block being irradiated at an angle. The test was set up so that the test beam and centerline of the receiver intersected at or close to an artificial cavity in the block. At first, considerable difficulty was encountered in determining which signals were coming from the defects. However, as experience was accumulated certain repetitive patterns were evident and interpretation became easier. The technique followed was to change the irradiating angle and observe the differences in the received pattern. At about 20° the front surface echo disappeared and the back surface echo was severely attenuated (Figure 24). However, when a defect was in the line of sight of the sending transducer, a strong signal was picked up by the receiver. Figure 25 is a 21°, 2½ MHz C scan map made of an AXF-9Q test block and the results compare quite favorably with a conventional scan.

The loss of the front signal does create a small problem in ranging the defect and setting the proper gating locations. This will create some problems in implementing the test but will not affect the basic validity of the test. It is intended to repeat this experiment with ATJ-S graphite after a suitable test block has been formulated. Because of actual volume of noise and potential variety of it, the spectral analysis approach would appear to be a natural adjunct to these studies and will be so applied.

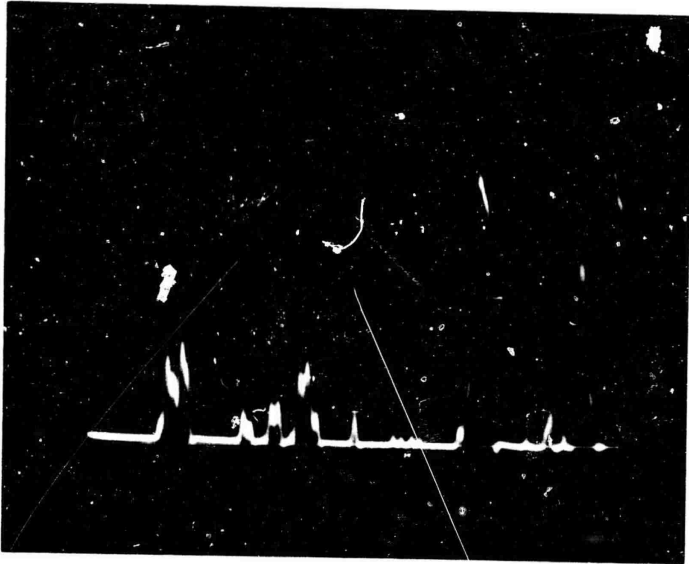
v. ACOUSTIC HOLOGRAPHY

Another new approach to ultrasonic inspection is acoustic holography. In this approach a coherent acoustic low amplitude interferometric wave pattern created on the water surface by an immersed CW ultrasonic test beam as it interacts with the structure of a part is reconstituted as an optical image by coherent laser light. The reviewer thus observes not only a real time image of the original part but of internal features as well, much in the manner of a fluoroscope. This can be viewed directly or photographed, and even motion pictures have been made of moving objects. The use of this technique has quite rapidly developed to the point where it has "gone commercial" with a unit made by Holotron. This unit was demonstrated at the November 1969 Metal Show with surprisingly good results. Accordingly, arrangements were made to evaluate the system with the ATJ-S standard defect block. Results indicated that the pulse level in the present unit is too low to effectively penetrate the ATJ-S and generate a pattern for holographic analysis. Holotron further reported that this problem is not unique to graphite and that they are moving to increase both pulse power and the frequencies obtainable in their unit. These modifications are expected to be complete this summer at which time further tests will be made.

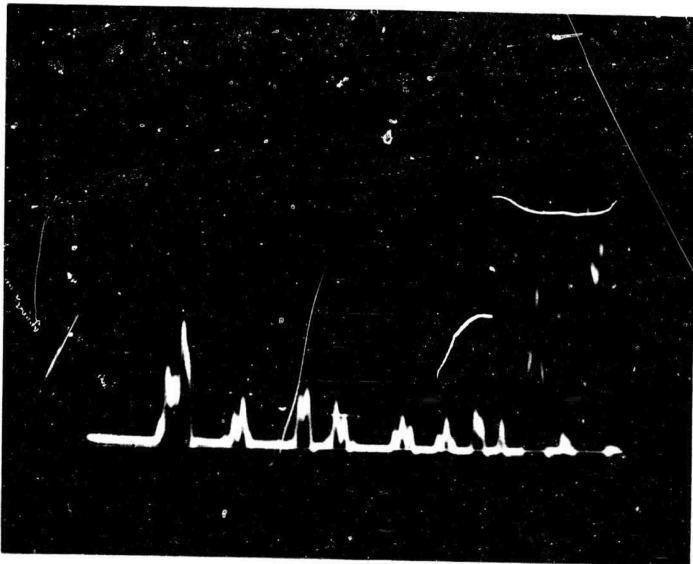
RADIOGRAPHIC STUDIES

I. LAMINOGRAPHY

Although there have been several funded studies on the application of radiography to graphite flaw detection problems, it was felt that several other avenues



Defect



Moved Off Defect

NOT REPRODUCIBLE

Figure 24

Delta Scan of AXF-9Q Graphite At

Angle $\angle 21^\circ$ At 2.25 MHz



NOT REPRODUCIBLE

Figure 25

Delta Scan of AXF-9Q Graphite
Sample #1 @ 2.25 MHz Angle 21°

of approach were available for this study.(7) (18) (19) In the interrogative area there was one method which looked especially promising for detecting small defects in relatively thin sections. The principal of this method is that the film and part are rotated in the beam such that the motion of only a relatively thin section of the part is synchronized with that of the film.(Figure 26) When done properly all other sections are moving either faster or slower than the film thus becoming "smeared out" and only clear image is that of the sync'ed section. The method was originally developed for medical applications and has long been used for detecting lung tumors. This technique was evaluated for graphite by Wallouch(17) for large billets with some promising results but a more sophisticated approach described by Moler in 1968 was used as the starting point for this work (4).

This technique demonstrated a marked capability for being able to examine individual strata in laminated circuit boards having vertical separations between layers of 0.004 inch. It was reportedly able to detect circuit cracks having a width of .0007" or greater. It was anticipated that with this method we could evaluate and compare adjacent thin layers of the material for conditions such as porosity, voids, cracks and small inclusions. By looking, in effect at very small slices of the subject item, these conditions will represent much higher percentages of effective section thickness than they do in the original billet or shape so that detecting them should be far less difficult than is the case at present. It was recognized that the necessity for making separate films for each layer represented a significant cost and time factor in applying this method, but if basic feasibility could be shown then the use of advanced techniques such as an x-ray sensitive vidicon with a storage tube output incorporated into a three-dimensional scanning system could be considered as a means of overcoming many of the difficulties in utilizing this technique. At the time this contract started a prototype unit based on Moler's general description was under construction. First tests with the unit were unsatisfactory and discussions with Dr. Moler indicated that a precision bearing support and a higher level of synchronization would be required to eliminate our troubles. This would require a complete redesign of the system which, in view of the other avenues of approach being investigated, was not felt to be worth the effort involved. It is intended to reevaluate the situation later in the program when the advantages of other NDT methods are in better perspective.

II. CONTRAST ENHANCEMENT

The principles of contrast enhancement are not new⁽⁴⁾. Basically they are applied to radiographic films to extract more information than the unaided eye can detect. Several basic techniques are available and new approaches appear on the market from time to time. Experience of the writer has been that in many cases these units can achieve truly remarkable improvements in radiographic sensitivity and detail.

One of the simplest approaches is the use of impregnants with relatively high atomic numbers and therefore good x-ray absorption properties such as tetra bromoethane(20) for delineation of porosity and small cracks open to the surface. This has the advantage over traditional alcohol or MEK wipe tests in that it provides a permanent record which is far more definitive than the visual criteria used for the wipe test. A second approach is the use of simple positive prints on either a second sheet of x-ray film or on E finish high contrast printing papers. These can easily double the penetrameter sensitivities obtained in the radiography of

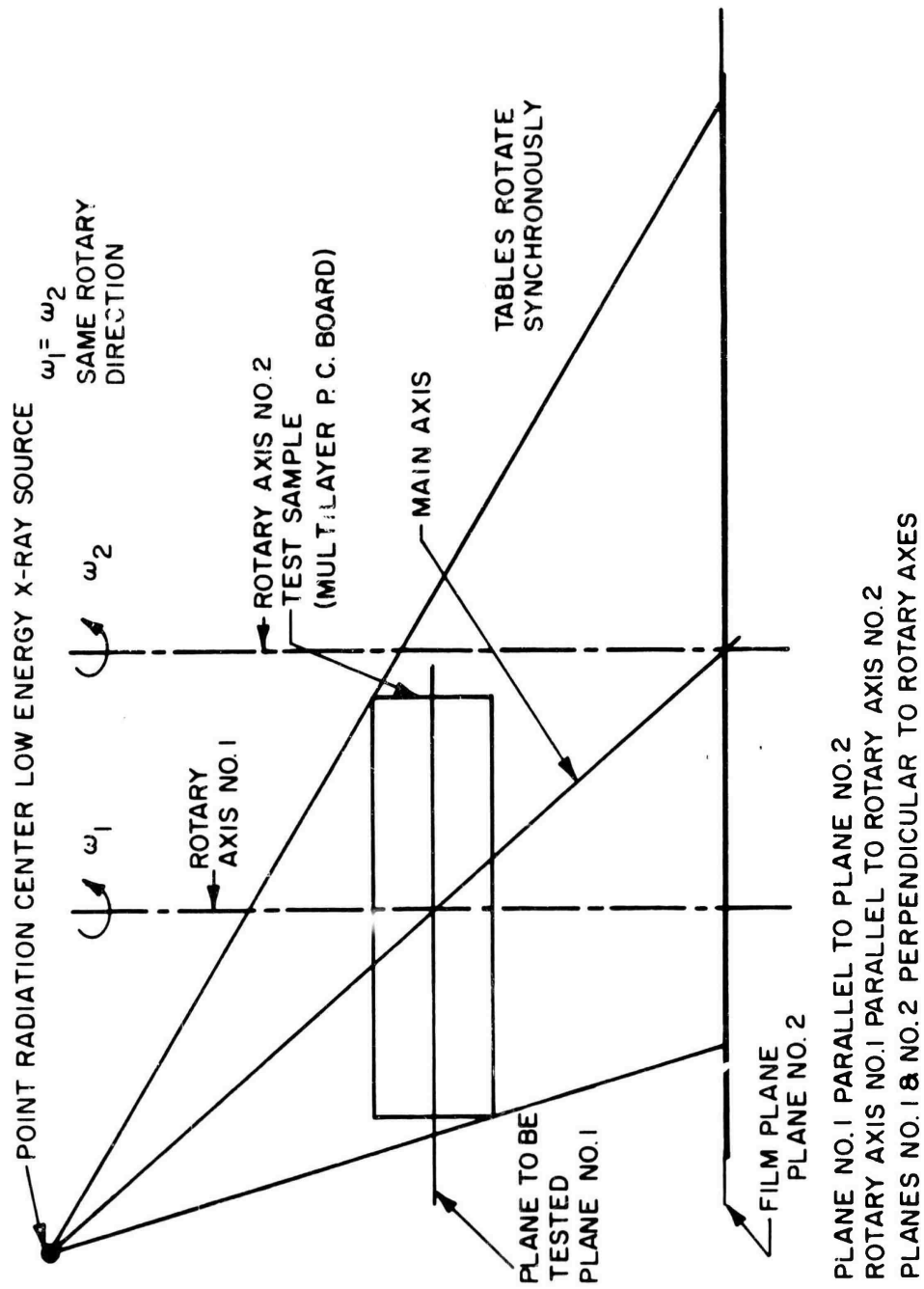


Figure 26. Diagram of Advanced Laminography Facility

many low Z absorbers. Of greater sophistication are the electronic TV based systems. One such system is the GE Explorex which is sensitive to film density variations below the human eye threshold of visibility ($\sim \Delta D = .01$) and by a technique known as edge enhancement produces almost three dimensional displays in real time. Of greater sophistication is the Special Data Systems black and white film to color converter. This is somewhat similar to the Explorex in that it scans the film with a TV camera but rather than present a second black and white image converts it into a real-time image having ten discrete colors plus black and white. The total values and range of film densities converted are adjustable so that great versatility is possible in the type of display presented. However, this system has a minimum density discrimination of about 0.15 density units which is well above the 0.01 density unit variation to which the eye is sensitive. SDS has a thirty color unit (plus black and white) available which should bring it closer to human eye capabilities. Because of the added dimension of color the density difference may not be as significant as it appears at first glance. It is planned to perform a more extensive evaluation of this system during the second year of this program. Another system considered was a digital conversion approach marketed by Information, International. This system is based on the work done by JPL in enhancing the lunar and Martian photographs by digital computer techniques. The system has shown great potential in detecting film elements which can be defined mathematically such as linear cracks or discrete voids such as might be encountered in welds. However, such definition is not felt to be practical for graphite materials where fine porosity and randomly oriented cracks are the dominant mode of material discrepancy and no further investigation is recommended at this time.

Perhaps the ultimate technique in film conversion techniques is the photographic extraction technique being developed at Philco Ford under AFML Contract F33615-69C-1607. This is theoretically capable of making an almost infinite number of density divisions for the most detailed analysis of film data possible. However, it is an off-line technique and at present requires a high degree of experience in making the conversions and interpreting the results. It is understood that Philco Ford is working on an automatic system for processing the films so the above comments may no longer be valid.

Returning to "conventional" radiography, perhaps the most original approach is by the Westinghouse x-ray Division. Here the x-ray beam is directed to a fluoroscope image amplifier rather than film and through a TV link to a CR storage tube. A second image is then created at a slightly different beam voltage and superimposed on the original. This second image has a slightly different set of contrast characteristics which varies according to the Z number and density of the constituents. Electronically subtracting the second image from the first leaves only the differences for viewing. Relatively constant visual elements such as inclusions disappear from view while porosity fields are greatly enhanced. It is true that the SOA of the radiographic response characteristics of image amplifier tubes is inferior to that of film but steady progress is being made in this area so the use of this approach cannot be dismissed out of hand for this work. At their present state of development and cost, many of these methods offer attractive opportunities toward improving the quality of radiographic inspection in all materials not just graphite. Unfortunately, it has also been observed that a vast communications gap exists in this area. Most of these methods were not developed with industrial radiography foremost in view. They were developed either with medical needs in mind or for use with photographic (particularly aerial photography) films of far lower film density ranges than x-ray film. Consequently, the traditional salesman/customer relationship is often reversed. We must seek the vendor out and make him aware of our needs.

It is suggested that one way of approaching this problem is the use of the various symposia sponsored or co-sponsored by the Materials Lab. Although these meetings are often attended by people working either in the development or application of advanced NDT methods, it is usually not the case that they or their management are up-to-date in all areas of the field. By inviting the vendors of some of these advanced concepts in radiographic film viewing to demonstrate their items, a valuable dialog would be set up which could well hasten the development of improved products for industrial needs on one hand and their expeditious introduction into the field on the other. It is true that conventional NDT symposia sponsored by non-governmental agencies could also serve this purpose but personal observation leads the writer to believe that the presence of AFML at such a meeting could more effectively catalyze the development of this dialog than might ordinarily be the case. The accomplishment of this objective would work to the benefit of many materials programs where radiography is an important NDT tool.

EDDY CURRENT STUDIES

As with the other methods of NDT there have been several studies on the application of eddy current techniques to graphite.⁽²¹⁾ There have also been several studies notably at ANL⁽⁹⁾ and BNWL⁽²²⁾ on the development of advanced eddy current concepts primarily for nuclear fuel element evaluation. One particularly interesting approach was the pulsed eddy current system developed at ANL. This unit was originally developed to inspect cylindrical uranium fuel elements bonded by sodium metal to a stainless steel jacket. In developing this unit it was desired to inspect the ID of the jacket and OD of the uranium for non-wetted areas and the sodium for bubbles. In so doing, it, in effect, looked down through the various layers of the system in a sequential manner, thus creating a sort of eddy current lamino-graph. We intend to adapt this concept to the inspection of graphite. To this end the ANL circuit diagrams have been obtained and the construction of this unit has been started. It is anticipated that building and debugging of the unit will require 4-6 months. In the meantime studies have been started using an available RADAC 302 commercial eddy current unit. This is widely used in industry for a variety of metallic material inspection problems and with it, we planned to establish basic parameters in regard to frequency selection, probe design, and other factors in eddy current testing. First results in these studies showed that the unit appeared to possess insufficient resolution to detect any of the holes in the 1" AXF-9Q specimens supplied although the frequency (4 KHz) was adequate to penetrate the full thickness of the block. A standard RADAC 1/4" diameter differential probe was used for this work and better probe designs may also be available. A more advanced NDT system, the Nortec NDT-6 is now in the process of being procured and the adaptability of this unit for these studies will be checked out when it is received.

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13. ABSTRACT This report summarizes the first year's effort to develop more sensitive techniques for detecting and evaluating flaws in graphite. On the basis of preliminary studies, it was concluded that the potential areas of improvement in the state-of-the-art lay both in the interrogative and interpretative aspects of NDT - that is in the techniques of introducing the test energy and generating the test signal on one hand and extracting it from other non-information bearing or noise signals on the other. In regard to improved interrogative techniques particular emphasis was placed upon developing a better understanding and control of ultrasonic focused pulse echo inspection techniques to provide maximum response to small defects and the demonstration of the feasibility of delta scan ultrasonic inspection for ATJ-S and AXF-9Q grades of graphite. Other areas of interest for this work were an investigation of laminographic X-ray techniques and a basic definition of eddy current parameters leading to a possible application of pulsed eddy current techniques to graphite inspection. In the area of interpretation, primary emphasis was on improved techniques for deliniation of small defects on X-ray images and the application of signal processing, especially spectrum analysis, techniques for analyzing the ultrasonic responses received from various types of defects in graphite. Results of the first year's work have defined the limitations of "conventional" pulse echo testing and demonstrated the basic feasibility of delta inspection for graphite inspection. A listing of advanced techniques for x-ray film enhancement is also included. Next year's work will explore more fully the area of utility of the delta system and spectrum analysis for ultrasonic inspection. Efforts will also be made to evaluate more fully the capabilities of a modified laminographic for			

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advanced applications such as graphite bonded to pyrolytic graphite for nose tips and rocket nozzles.

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Graphite						
Ultrasonic Testing						
Radiography						
Eddy Current Testing						
Delta Scan						

Security Classification