

**ACOUSTIC EMISSION INTEGRITY ANALYSIS
OF
PRESSURE VESSELS AND PIPING**

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ABSTRACT

Acoustic emission analysis techniques are now being applied in industry for the detection and location of defects and leaks in commercial structures and pressure systems. It has proven to be capable of rapidly detecting and locating multitudes of flaws in large complex structures under field test conditions. Analysis capabilities range from the detection and location of micro-cracking to the identification and location of significant crack growth. This new nondestructive test tool utilizes the micro-acoustic signals that emanate from material flaws. It utilizes the high frequency noise generated by leaking gas or fluids to detect and locate leaks in pressure systems such as vessels and piping.

Acoustic analysis tests of nuclear pressure vessels have resulted in the detection and accurate location of flaws and defect regions. The defect sites were cross-checked and confirmed using standard nondestructive test techniques. Tests conducted on pressure and drill piping have enabled the detection and location of material flaws, corrosion and leaks.

1. INTRODUCTION

Acoustic emission analysis techniques are now being applied in industry for the detection and location of defects and leaks in commercial structures and pressure systems.

The major effort, to date, has been directed at the integrity analysis of pressure systems in the nuclear, petroleum and chemical industries. However, systems and services are available and applicable to a wide variety of structures.

This new nondestructive (NDT) test tool utilizes the micro-acoustic signals that emanate from material defects in structures under stress to detect, locate, and categorize material flaws. It utilizes the high-frequency noise generated by leaking gas or fluids to detect and locate leaks in pressure systems such as vessels and piping.

Acoustic analysis technology provides a means for eliminating the laborious search and find procedures required by present NDT techniques and leak detection systems. Acoustic analysis has the sensitivity to define not only the growing flaws in a structure, but also the potential flaw growth regions provided by weld slag, porosity, and material inclusions. Acoustic analysis does not suffer from the problems associated with conventional ultrasonics techniques,

such as beam refraction from stainless cladding interfaces and the inability to penetrate cast structures and dissimilar metal weldments.

It differs significantly from standard NDT techniques in that it is a dynamic test which analyzes the response of structural flaws to operational stress parameters.

Experience gained on large petroleum vessels, nuclear vessels, and piping systems evidence that the flaw detection and analysis capabilities of acoustic emission technology provides a powerful new integrity analysis tool. When applied to leak detection, it has proven to be sensitive, rapid and accurate. This report presents the results of recent acoustic integrity analysis service tests conducted by Jersey Nuclear in the field on nuclear pressure vessels and on transmission and pressure piping.

2. SYSTEM DESCRIPTION

The Jersey Nuclear ACOUST-I acoustic analysis system, used for field testing, is located in a self-contained mobile test laboratory shown in Figure 1 and 2.

The ACOUST-II system, shown in Figure 3, is a small air-transportable system used primarily for integrity analysis; defect location can be accomplished by post analysis.

The ACOUST systems use the sharp resonant frequency of a piezoelectric crystal for detecting acoustic emission. Various types of these detectors are used according to the particular test requirements. Figure 4 shows several commercially available transducers which are suited to specific test needs.

The frequency of operation is usually in the 100 kHz to 300 kHz region. This specific frequency range has been found to be high enough to avoid mechanical noise interference from operating machinery, and flange and bolt movement; yet it is low enough to avoid the high signal attenuation rates observed in the transmission of high frequency signals through metal.

Figure 5 shows a block diagram of the ACOUST-I system which is used for amplification, signal conditioning and analysis of the detected acoustic emissions. The ACOUST-II circuitry differs only in the lesser number of transducers that it uses (8-12) and the fact that it does not contain a digital computer for on-line defect location.

Two stages of special amplifiers are used prior to analysis. These amplifiers can produce a combined gain of 10^7 if required; however, lower gains are normally used for large structural tests.

The ACOUST systems use a Time Analysis Computer (TAC) in their data analysis system. It is designed to compute the differences in arrival time of each detected acoustic signal at several transducers and to accumulate the resulting data for visual monitoring and computation of the emitting source location at any desired time by use of a small digital triangulation computer. The triangulation computer incorporated in the ACOUST-I system, utilizes the time analysis data, which is read out at the discretion of the operator, along with data input concerning each transducer location on the structure under test, to calculate the geometric location of the detected defects.

In addition to the flaw location circuitry, selected transducer outputs are utilized by special "energy release" circuitry which provides continuous surveillance of all acoustic emission activity. Significant crack growth (crack growth that would eventually damage the

structure), should it occur, is evidenced by a characteristic acoustic emission energy release pattern. Growth of significant flaws is immediately sensed by the energy release circuitry, and displayed on a strip chart recorder in order to provide early warning of critical defects. This information is confirmed by cross-checking with the rate of data accumulation in specific time domains of the TAC. Tests conducted on vessels, in addition to acoustic emission test results obtained on experimental structures purposely stressed to failure, have shown that characteristic energy release patterns are normally detected at early low-stress periods of the test. The ACOUST systems therefore, provide early warning of the onset of incipient failure and allow corrective action to be taken.

A characteristic energy release pattern for significant flaw growth is shown in Figure 6; a similar pattern for insignificant flaw movement is shown in Figure 7.

The acoustic behavior of materials under increasing stress is further illustrated qualitatively by the curve shown in Figure 8. Defects undergoing growth that is insignificant to the structure's integrity, release acoustic energy at some comparatively low value, as shown by the left horizontal portion of the curve. This value is relatively constant with increasing stress. Should a defect undergo more rapid growth, the acoustic energy release rate increases.

The release rate continues to rise during critical crack growth, reaching extremely high values as failure is approached. Experience has shown that most common structural materials stressed above the Nil-ductility temperature follow a curve as shown in Figure 8 by the solid line. Brittle materials appear to approach failure along the dotted line.

Warning of the onset of incipient failure is provided at an early time by inflection of this curve in the region of the small arrow. The region is represented by the acoustic pattern shown in Figure 6.

For the detection of leaks the ACOUST systems are used to detect the characteristic wide frequency range pulsating signals generated by fluid or gas flow. Attenuation techniques are normally applied for location of the leak regions. For certain leak conditions, where two phase flow is created by a leak (fluid-gas or water-steam), the Time Analysis Computer and triangulation computer may be applied for definition of leak location.

In addition to periodic integrity analysis, acoustic technology is applicable to the continual on-line integrity assurance of pipe lines and other pressure systems transmitting noncavitating liquids and gases.

3. TEST PROCEDURES

ACOUST system application techniques are essentially identical regardless of the type of structure to be tested.

The acoustic emission phenomena as applied to flaw detection, requires that stress be applied to the materials under test. Applied stress is essential whether its magnitude is small or large compared to the material yield strength. However, large values of stress are seldom required for the successful application of acoustic analysis technology.

In the testing of pressure systems, it is normally advantageous to apply hydrostatic or pneumatic pressure through a steady pressure increase. Structure loading or thermal stress

may be used in testing structures that do not lend themselves to either hydrostatic or pneumatic stressing.

Prior to testing, the structure is surveyed and transducer locations are established based on the size and shape of the vessel. Transducers are then mounted on the structure. The exact locations of the transducers are noted and recorded in relation to structural design coordinates. Preamplifiers are attached to each transducer and connected to the mobile laboratory by coaxial cable or micro-wave transmission. An artificial acoustic signal is also connected for calibration purposes.

Upon the initiation of structural stress, acoustic data acquisition and on-line analysis is begun. The system channels are processed and displayed on visual display screens and chart recorders for monitoring possible critical crack growth during the test. When the ACOUST-I system is used, the geometric locations of detected flaws are periodically computed during the performance of the test. The information is printed out and displayed in permanent record form. The acoustic signals from all channels are recorded on magnetic tape for record purposes and post analysis.

Post test analysis is performed on-site and is directed at confirmation of the results accumulated during the test and for the identification of all detected sources or flaws regardless of size or significance. These sources may represent suspect structural regions which contain small insignificant defects that represent no immediate threat to structural integrity, but are potential sites for future crack growth.

4. REPRESENTATIVE TEST RESULTS

The ACOUST system has proven to be capable of rapidly detecting and locating multitudes of flaws in structures ranging in complexity from nuclear pressure vessels to drilling and gas transmission pipe.

The following test describes the results of a few representative tests conducted using the Jersey Nuclear ACOUST systems.

a) Integrity Analysis of a Nuclear Pressure Vessel

Acoustic analysis techniques were used to assess the integrity of a large, complex nuclear pressure vessel, a sketch of which is shown in Figure 9. Specifics related to this vessel have not as yet been released by the customer for dissemination. However, it is hoped that the generalized results presented here will serve to represent the inherent capabilities of acoustic technology as an integrity analysis tool.

The purpose of this test was to demonstrate to the customer the potential of the acoustic analysis technology for pre-service and in-service inspection of nuclear pressure vessels.

The vessel was instrumented as shown in Figure 10 in a manner that would allow two distinct test phases. The vessel was hydrostatically pressurized to one half the maximum test stress during Phase I; 20 of the 27 transducers were active during this phase. Phase I represented a typical shop hydrostatic test in which essentially all vessel surfaces are accessible.

Phase II was conducted utilizing those transducer positions that would be accessible during in-service testing, ie. transducers 1 through 20. The hydrostatic pressure for Phase II encompassed the region from one half of the maximum, up to maximum test stress. The results of the two test phases were compared following the test, to determine the sensitivity and accuracy achieved by utilizing only in-service accessible transducers.

The ACOUST-I system was used to detect, locate, and to assess the significance to structural integrity of all vessel defects.

The total test results were compared with ultrasonic results obtained following the test, to determine the overall accuracy and reliability of the acoustic analysis system as a non-destructive test tool.

b) Test Results

Thirteen defect regions, analyzed as insignificant to the integrity of the vessel, were detected and located during the test. These defects regions are represented in Figure 10. Ultrasonic testing conducted immediately following the test confirmed the presence of 10 of the indicated defects; two of the defects regions were in locations inaccessible to ultrasonics and were thus not ultrasonically inspected. One of the defect locations was not examined by ultrasonics due to an oversight. Four of these defects had been previously located in production x-ray tests. As shown in Figure 11, the ten defects that were confirmed with ultrasonics were identified as minor voids, slag inclusions, and possible lack of weld penetration.

It should be reiterated that none of these defects were acoustically identified as significant to the integrity of the vessel. They were located and confirmed with ultrasonics only to demonstrate the accuracy and sensitivity of acoustic analysis techniques.

The results of test Phases I and II correlated well, with the qualification that the transducer locations used in Phase II permitted approximately 20% less accuracy in precise location of the defect regions. Average defect location accuracy was approximately ±4 inches.

The above described tests were conducted on a vessel whose nozzles were plugged by welded closures. The majority of the nuclear vessels constructed in the United States are hydrostatically tested prior to acceptance by closing the nozzle with specially designed nozzle plugs. Acoustic scoping tests recently conducted on two large U.S. manufactured nuclear vessels have indicated that these plugs generate considerable acoustic movement noise during the hydrostatic test period. The acoustic background noise can prevent the accurate acoustic integrity analysis of a vessel during its acceptance hydrostat.

Methods of modifying the plug designs to lessen the movement noise, is now being considered.

5. ACOUSTIC INTEGRITY ANALYSIS OF PIPING

a) Transmission Pipe

Acoustic integrity analysis testing is being conducted on long runs of steam, gas, and chemical transmission pipe. Transmission pipe size has ranged from 8 inches to 42 inches in diameter. Wall thickness has ranged from 0.2 to 0.6 inches.

The transmission line tests have shown that transducers may be placed from 500 to 1,000 feet apart and still provide adequate sensitivity for detecting and locating critical flaws that would eventually lead to failure of the lines.

Tests conducted for the location of leaks have shown that similar transducer spacings are applicable for the leak integrity testing of long runs of piping. Figure 12 shows a typical transducer installation on a buried gas pipe.

In addition to the capability for locating structural cracks and thru-wall leaks, tests conducted on gas transmission pipe have shown the capability of detecting and locating corrosion areas.

In a recent test series, 104 feet of 14 inch pipe was repeatedly stressed to its normal operating pressure. Fifteen deep corrosion pit sites were acoustically identified and located. Figure 13, shows a typical pitting location. Seven of these regions were identified as being larger (deeper) than the rest. Out of these seven, one eventually leaked at high pressure and one caused pipe failure at pressures approaching twice the normal operating stress.

b) Drill Pipe

The fatigue cracking and failure of drill pipe is a specific problem for the petroleum industry. Jersey Nuclear, working in conjunction with one of the large petroleum concerns in this country, is in the process of developing field application techniques for the integrity analysis of inuse drill piping using acoustic analysis techniques.

Procedures for applying the technique in a quick and reliable manner under field drilling conditions are now being developed. These procedures will allow the integrity analysis of drill pipe as it is pulled from the well and prior to being placed back in the drill string.

Figures 14, 15, and 16, show a drill pipe field testing area, and pipe rack.

6. CONCLUSIONS

The acoustic analysis technology incorporated in the ACOUST systems has proven to be capable of rapidly detecting and accurately locating flaws in structures ranging from complex nuclear pressure vessels to simple piping systems. The analysis capabilities range from the detection of inclusion initiated void formation to the identification of crack growth significant to structural integrity. The system has the capability of distinguishing between significant and insignificant flaws; it can detect minute pressure leaks, cracks, and corrosion pitting in long runs of pressure piping.

It is the author's belief that acoustic analysis technology provides a previously unattainable level of capability in the nondestructive testing field.



Fig 1

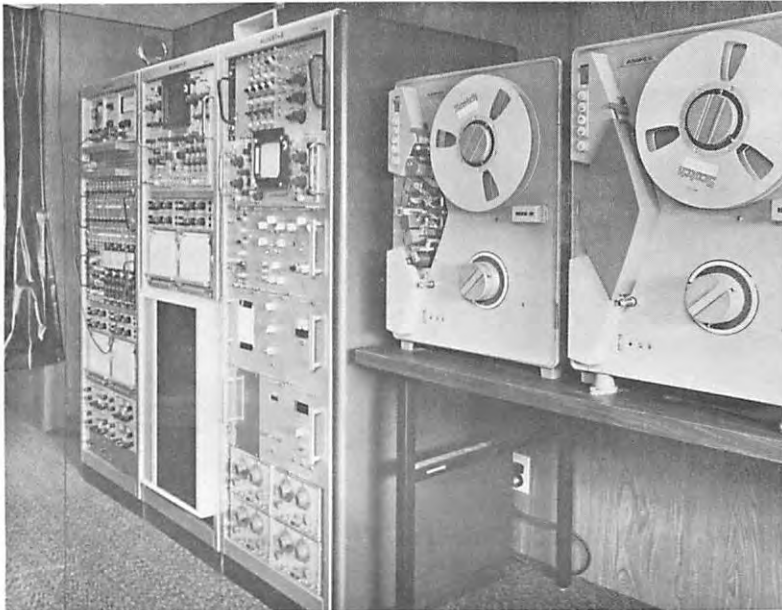


Fig. 2

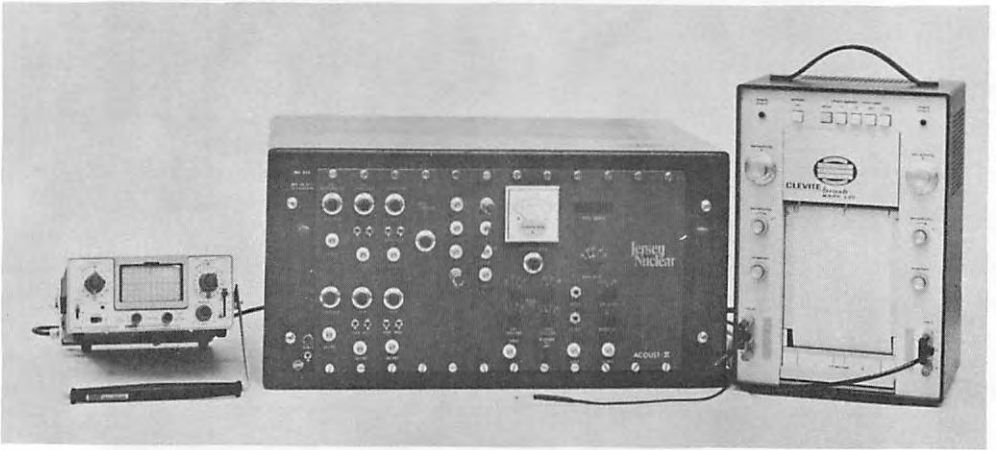


Fig. 3

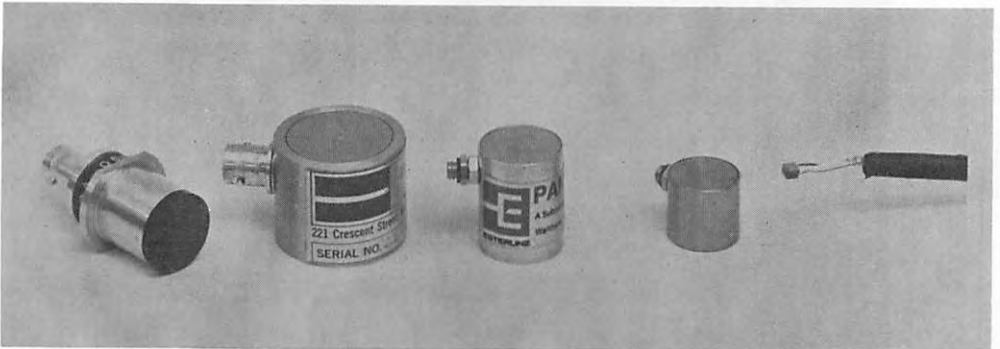


Fig. 4

ACOUST-I NONDESTRUCTIVE TEST SYSTEM

FOUR CHANNEL BLOCK DIAGRAM

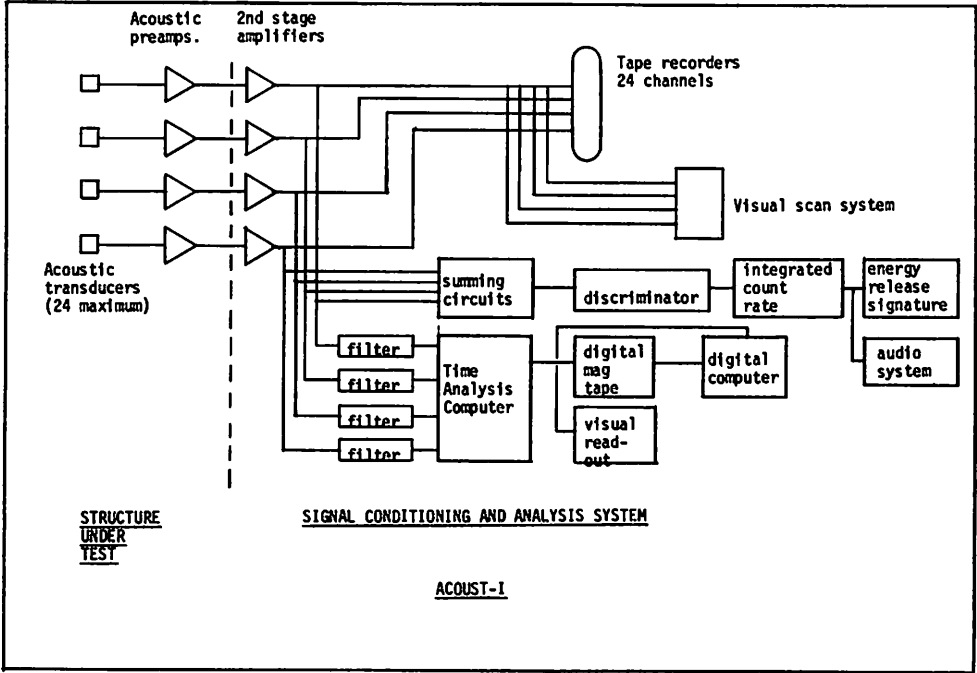


Fig. 5

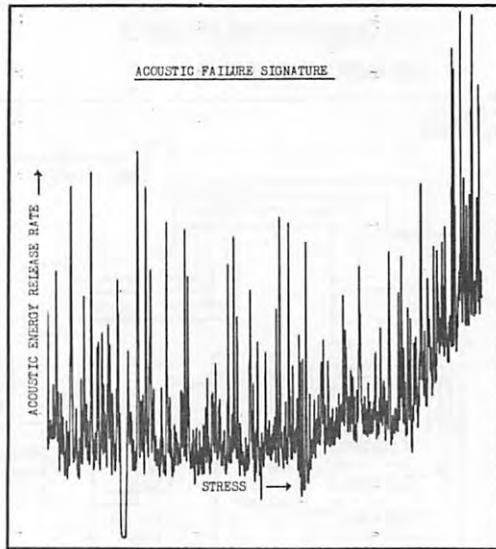


Fig. 6

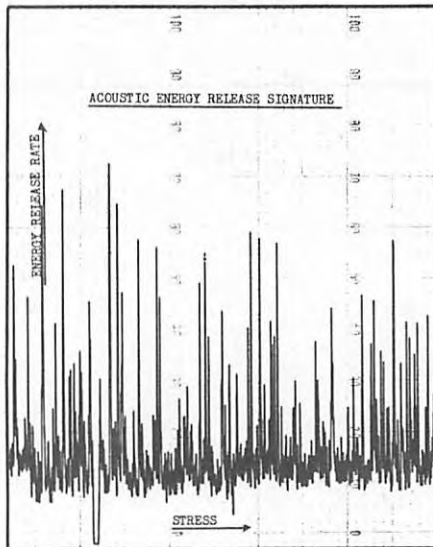


Fig. 7

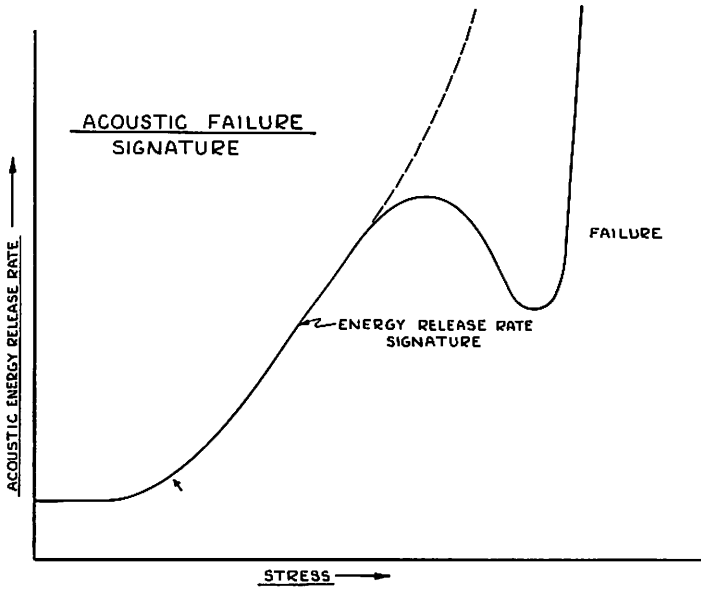


Fig. 8

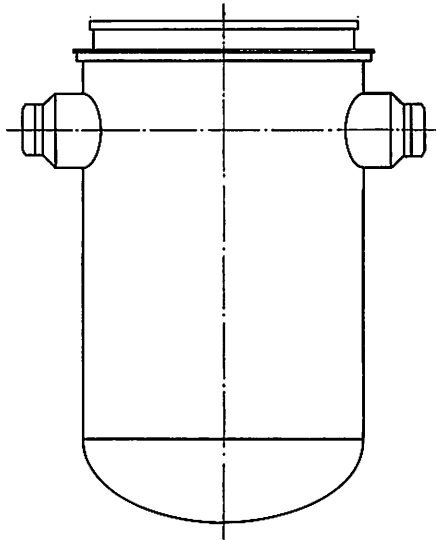


Fig. 9

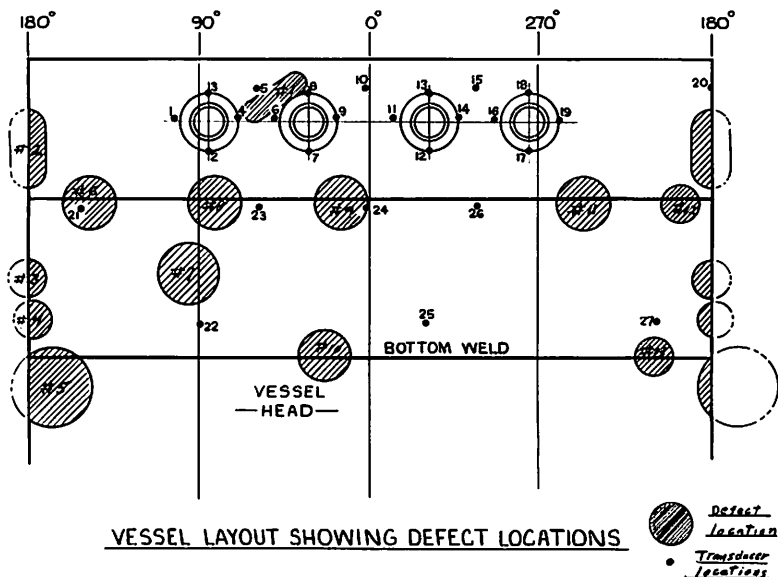


Fig. 10

POST-TEST CONFIRMATION

SOURCE	ULTRASONIC CHECK (ON SITE)			X RAY CHECK (PRODUCTION RECORDED)			VISUAL	DESCRIPTION
	CHECK	SENSITIVITY	REFERENCE STANDARD	FILM	CHECK	SIZE		
1	—	—	WELL SCREEN DEFLECTION FROM 3/16 INCH DIA. FLAT BOTTOM HOLE	—	—	—	—	Inaccessible for N.D.T.
2	—	—		15,16	No	—	—	Inaccessible for N.D.T.
3	YES	100I +6 db 100I +8 db		11,12	No	—	No	Small Weld Slag Inclusions
4	YES	100I +6 db 100I +8 db		9	Yes	1/4" X 1/16"	No	Small Weld Slag Inclusions
5	YES	40I		41	Yes	1/8" X 1/32"	No	Small Slag Inclusion
6	YES	80I 100I +4 db		44	No	—	No	Minor Voids/Inclusions
7	YES	40I		—	—	—	No	Small Slag Inclusion
8	YES	80I 100I +2 db		223	Yes	1/16" dia.	No	Minor Voids/Inclusions
9	YES	100I 60I		53,54	No	—	No	Minor Voids/Inclusions
10	—	—		30,31	No	—	No	Not Examined by Other N.D.T.
11	YES	60I		235	Yes	1/16" dia.	No	Weld Pore.
12	YES	90I 80I		65,66	No	—	No	Minor Voids/Inclusions
13	YES	By pretest U.T.		18,19	No	—	No	Small Pore Type Indication

Fig. 11



Fig. 12



Fig. 13

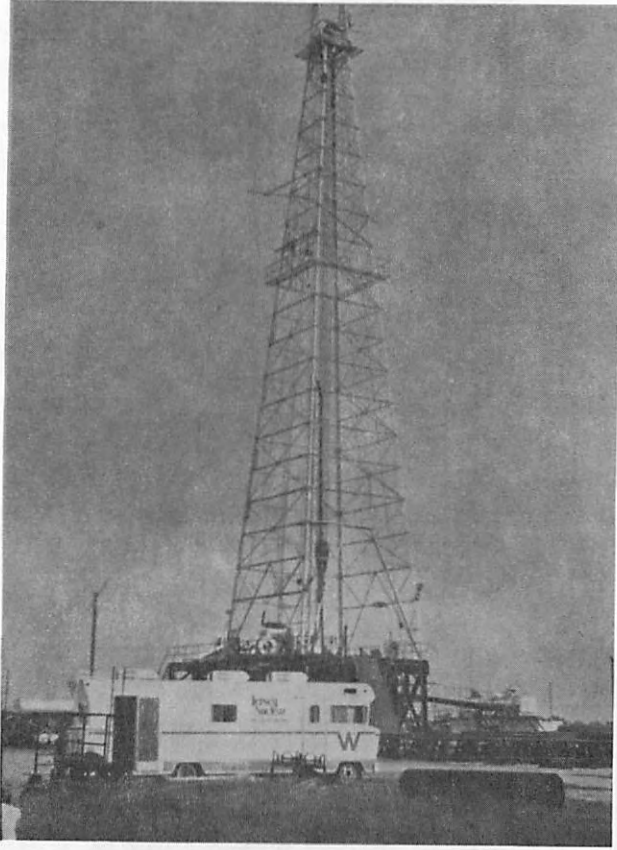


Fig. 14

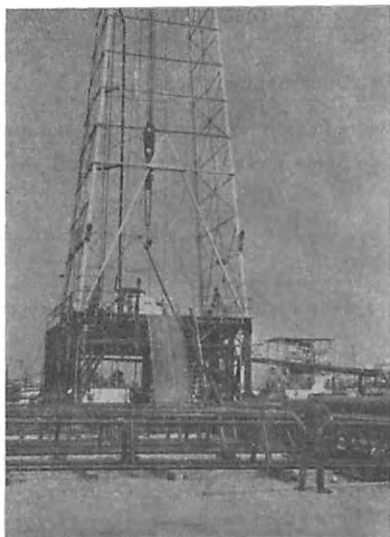


Fig. 15

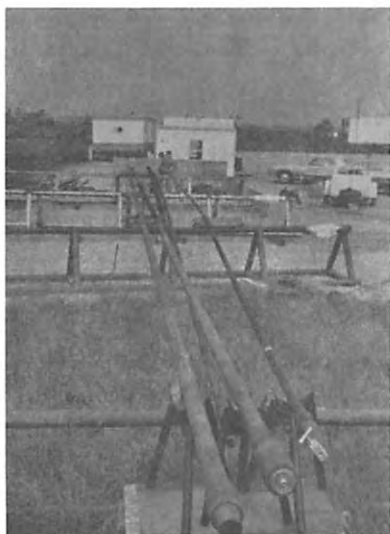


Fig. 16

DISCUSSION

Q J. EHRENTREICH, Commission, Brussels

1. How many of the defects found in your pressure vessel examination had to be repaired ?
2. What is your experience using this method for the surveillance of reactor pressure vessels in operation ?

A D. L. PARRY, U. S. A.

1. None of the detected defects were significant to the integrity of the vessel and none therefore had to be repaired.
2. The operating noise tends to obscure acoustic information.

Q H. BASCHEK, Switzerland

1. Up to which extent the acoustic method can be used for in-service inspection ?
2. Am I right in the assumption that the acoustic method cannot yet be used for leakage detection during reactor operation ?

A D. L. PARRY, U. S. A.

1. The acoustic analysis technology is recommended for application during three stages of plant construction and operation:
(1st) during vessel proof testing,
(2nd) after plant installation and prior to operation,
(3rd) during periodic shut down.
2. Yes, leak detection is very difficult with an operating plant.

Q D. O. HARRIS, U. S. A.

You mentioned using a periodic pressurisation of a reactor vessel during shut down to detect flaws by use of acoustic emission. Do you feel that the irreversible nature of acoustic emission could often result in not detecting cracks that are present ?

A D. L. PARRY, U. S. A.

We have found that the small less significant defect regions do not show up on repeated pressurisations, however, the large flaws that are significant to vessel integrity will appear during each stress cycle.