EIGHTH WORLD CONFERENCE ON NONDESTRUCTIVE TESTING
HUITIEME CONFERENCE MONDIALE SUR LES ESSAIS NON DESTRUCTIFS

2A8

INSPECTION OF NUCLEAR POWER PLANT PIPING WELDS BY IN-PROCESS ACOUSTIC EMISSION MONITORING

INSPECTION DES SOUDURES DES TUYAUX DANS LES CENTRALES NUCLEAIRES PAR ÉCOUTEMENT DES EMISSIONS ACOUSTIQUES

PRINE D. W. — NILES, ILLINOIS

GATX/GARD, INC. — UNITED STATES OF AMERICA

SUMMARY: The results of using In-Process Acoustic Emission Monitoring on nuclear power plant piping welds are discussed. The technique was applied to good and intentionally flawed test welds as well as production welds, and the acoustic emission results are compared to standard NDT methods and selected metallographic cross-sections.

RESUME : Ce compte rendu présente les resultats experimentaux d'une méthode d'inspection des soudures à tuyaux destines à les centrales nucleaires. Cette méthode consiste en écoutement des signaux acoustiques qui sont émis lors de soudage. La méthode a ete appliquée à des bonnes soudures, à des soudures comprennant des défauts intensionnels, et aussi a des soudures de série. Les resultats des émissions acoustiques sont y comparés avec les essais non-destructive standards et avec les sections droites metallographiques proprement choisies.

I. INTRODUCTION

When a material undergoes stress, several energy release mechanisms come into play. One of these is the release of acoustic energy. Many researchers have shown that useful information may be obtained on the stressed specimen by monitoring and processing, electronically, the acoustic emission, while the stress is being applied.

The welding of metals produces a unique situation, whereby stress is generated within the weld due to thermal effect as the weld bead solidifies and cools; thus acoustic energy is emitted from a weld as it cools without the need for applying any external source of stress. As early as 1968, Jolly[1] at BNWL, showed that acoustic emission could be used to detect flaws in welds during fabrication.

The acoustic emission generated by a weld in the process of formation includes microscopic sources such as dislocation unpinning, phase transformation, and micro-crack formations as well as macro-cracking noise. In addition to these sources of sound from within the weld, the arc, itself, produces acoustical, as well as electrical noise. If the welding process makes use of a solid flux such as submerged arc or stick welding, the flux cracks as it cools; and this is yet another source of acoustic emission from the welding process. The basic problem of detecting flaws in welds with acoustic emission during the welding process consists of sorting the multitude of different acoustic signals and choosing the desired (e.g., flaw) signals while rejecting the many background acoustic signals. This process is further complicated in an industrial on-line application by the introduction of extraneous noises such as grinding, hammering, and manipulating the object upon which the weld is being made.

GARD began study on the Acoustic Emission Weld Monitoring problem in 1971 under a Corporate funded effort aimed toward in-process weld monitoring of submerged arc welding on railroad tank cars. The experience gained in this work has led to the development of signal processing techniques which allow the detection of several common flaws under production in-process welding conditions for submerged arc welding on carbon steel tanks. In this previous work, to establish the sensitivity of acoustic emission to weld flaws, a series of intentionally cracked welds were generated along with "good" control welds. The acoustic emission was monitored during welding using standard commercially available equipment. The cracks were induced by contaminating the welds with copper. The results of the study on test welds was used to fix design parameters for a weld monitor for use on submerged arc welding of carbon steel tanks. The weld monitor is currently undergoing production tests in GATX's Sharon, Pennsylvania, facility.

The results of the on-going Corporate sponsored acoustic emission (AE)study have pointed out several distinct advantages AE has over more conventional NDT methods.

First of all, AE Weld Monitoring is an in-process real time inspection technique which detects flaws as they are made, not after the fact, as in conventional NDT methods. This aspect of AE is particularly useful in thick multi-pass welds since the possibility exists for achieving repair of faulted early passes before these faults are buried deeply in the weld by subsequent passes. The real time feature also provides the welder with an immediate warning of welding conditions which are producing flaws, thus allowing him to adjust his parameters and possibly produce less flaws than would normally be produced.

Further production cost savings are possible as a result of the real time aspect of AE because of reduced material handling. The flaws can be repaired on the spot without need for transporting the completed assembly to a testing area and returning it for repairing. This feature is especially attractive for large items such as heavy tanks, large diameter primary loop piping, or pressure vessels.

In addition to the real time feature of acoustic emission monitoring, the method has moderate cost associated with it in comparison to conventional NDT methods such as radiography; it is relatively simple to apply, and it lends itself well to automatic or semi-automatic testing.

Furthermore, results seem to indicate that acoustic emission is particularly well suited to the detection of cracks in welds. These are not only the most detrimental flaws in a weld because of their inherent nature to propagate, but are frequently difficult to detect with conventional NDT techniques, especially if they are sub-surface and not favorably oriented.

II. TEST PROCEDURE

The test plan consisted of monitoring a series of test welds, some of which were intentionally flawed and some of which were made good. The raw acoustic emission signals from these welds were tape recorded to allow repeated playback so that:

1) acoustic emission flaw sensitivity levels could be established, and
2) equipment parameters could be optimized to the particular peculiarities of nuclear welded piping.

The flaws were confirmed by radiography and other standard NDT techniques as well as sectioning and metallographic examination. After sensitivity levels were set and equipment parameters optimized, a production run was made in which actual nuclear production piping welds were monitored by AE and the results compared to standard ASME Code examination results. This step gave further confirmation of the correctness of the equipment settings and allowed for some additional fine tuning of final equipment design parameters.

The calibration test plan is outlined in Figure 1. The materials chosen, A-106 Carbon Steel and A312 T304 Stainless Steel, comprise the two materials used for the largest portion of piping in nuclear power plants. In addition to being representative of a major portion of the piping materials used, these alloys were chosen because of their ready availability.

The four welding methods chosen for the calibration tests cover the range from extremely acoustically quiet (i.e., TIG) to the relatively high noise of submerged arc, MIG, and manual stick. These methods are the most commonly used in nuclear pipe fabrication, and they were used in the calibration tests in the manner in which they are normally used during production fabrication.

		(1)	(2)	(3)	(4)	(5)
152.4 mm OD Carbon Steel	Root	MIG	TIG	TIG	TIG	TIG
	Balance	MIG	MIG	MIG	MIG	MIG
355.6 mm OD Carbon Steel	Root	TIG	TIG	TIG	TIG	TIG
	Balance	SA	SA	SA	SA	SA
152.4 mm OD Stainless	Root	TIG	TIG	TIG	TIG	MIG
	Balance	MTG	MTG	MIG	MIG	MIG
355.6 mm OD Stainless	Root	TIG	TIG	TIG	TIG	TIG
	Balance	SA	SA	SA	SA	Stick
Condition		Good	Good	Flaw	Flaw	Flaw
Bevel		C Bore	Maximum Misalignment	Maximum Misalignment	Maximum Misalignment	Maximum Misalignment

FIGURE 1 CALIBRATION TEST PLAN

The twenty welds are all multi-pass in nature, most averaging 4-6 passes for a total of nearly one hundred weld passes available for acoustic emission monitoring.

All the test welds were performed in a nuclear certified welding shop using certified materials. The finished welds were radiographed according to ASME nuclear standards. In addition to the calibration tests, two weeks of normal production nuclear welding on similar piping was monitored in two separate nuclear pipe fabrication shops.

The calibration samples were available for additional NDT or destructive testing, if necessary, and standard ASME nuclear code results made available on the production welds.

A block diagram of the equipment set up used for both the calibration and production tests is shown in Figure 2.

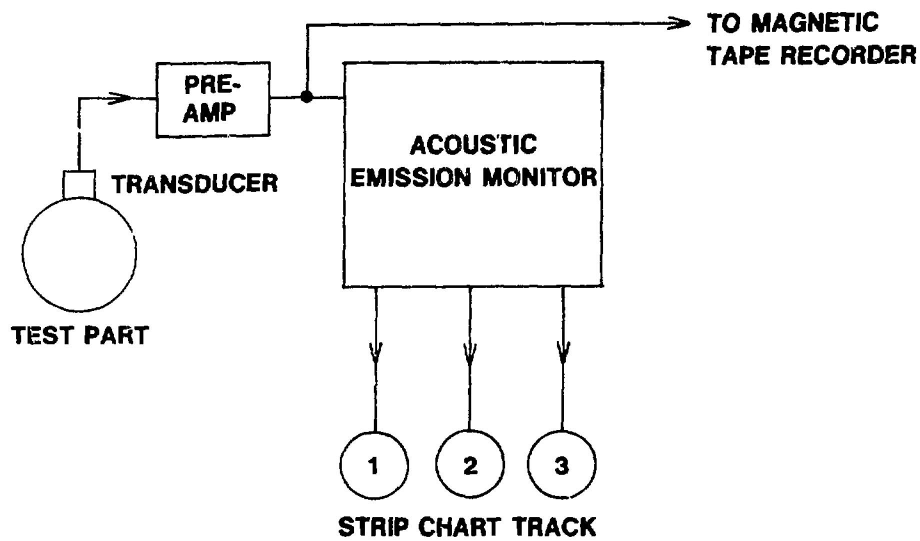

FIGURE 2 – ACOUSTIC EMISSION EXPERIMENTAL SET-UP

The equipment utilizes some commercially available acoustic emission monitoring equipment as well as some GARD designed circuitry. A combination of analog and digital circuitry is used to sort the incoming acoustic emission events and to automatically make decisions as to whether the events are background or flaw information. Four basic sorting processes are applied to the signals to allow separation of background from flaw data.

The first sorting process is simply a limitation of the frequency spectrum to be considered. The two factors of primary consideration are:

1) The portion of the spectrum used should be that in which the greatest amount of energy may be coupled to the equipment. This includes consideration of transducer design, as well as properties of the material under test, and the shock wave energy of events.
2) The portion of the spectrum used should be selected so as to minimize effects of outside electrical interference, such as nearby radio stations, etc. This problem may be minimized with adequate shielding. Frequency spectrum limitation hardware consists of a 100 KHz - 400 KHz bandpass filter.

The second sorting process is by the energy contained in each individual shock wave event. To obtain the most accurate evaluation of the energy of an event, a method known as Ring-Down Counting is used. This is a method familiar to those working in acoustic emission, and is described mathematically in a paper by K. Ono[2]. The result of applying Ring-Down Counting to acoustic emission is an electrical pulse, the amplitude of the events remaining unchanged. Selection is made by requiring the pulses to fall within an amplitude "window" (i.e., above a minimum amplitude, but below a maximum amplitude). These two sorting processes just described are functions of a Dunegan/Endevco Model 301 totalizer with slight modification by GARD, and external GARD developed circuitry. A third sorting process is accomplished by GARD circuitry. Sortingoccurs by fingerprinting signals according to the rate of occurrence of events. The correlation of the signals with weld faults has been established by both theory and experimental data. The fourth sorting process is a function of the spectral content of the events, and the shape of the event shock wave, modified by attenuation in the sample.

To allow repetitive replay for analysis purposes and for equipment parameter settings, the raw data in the calibration tests was recorded on an Ampex FR1300 instrumentation tape recorder. Processed data is plotted on a chart recorder.

III. TEST RESULTS

The processed acoustic emission data was fed to three channels on a strip chart recorder. Channels one and two are the normal two tracks of standard two channel strip chart while channel 3 is the automatic event marker track. Track 1 on the chart is the result of feeding Ring-Down counts to a D/A converter and then to the chart recorder. This track represents the information normally available in standard commercial acoustic emission monitoring equipment and is approximately proportioned to event energy. Track 2 plots those acoustic emission events which pass both the amplitude/energy window criteria and the high frequency discrimination circuitry. For stainless steel,track 2 is also the flaw alarm track. For carbon steel, which has been shown to have considerably more acoustic emission activity than stainless steel, an additional processing criteria is used, that is that the events in track 2 must occur at a time rate faster than some preset amount and also must produce greater than a preset number of events within some preset time limit. Events which satisfy this criteria are considered flaw signals and are displayed on track 3.

In Figure 3, we see an acoustic emission record for a section of 152.4 mm carbon steel pipe. The welding process is GMAW (MIG). Each major division in the horizontal direction represents 5 seconds. This record shows some production pipe fabrication shop background noise. Track one in the area marked W shows noise from repositioning the workpiece with a chain wrench. The weld starts in the upper left corner and proceeds left to right and then is continued in the lower half of the figure from left to right. In the bottom half, track 1, an area marked G is noise from an air driven grinder applied to the workpiece.

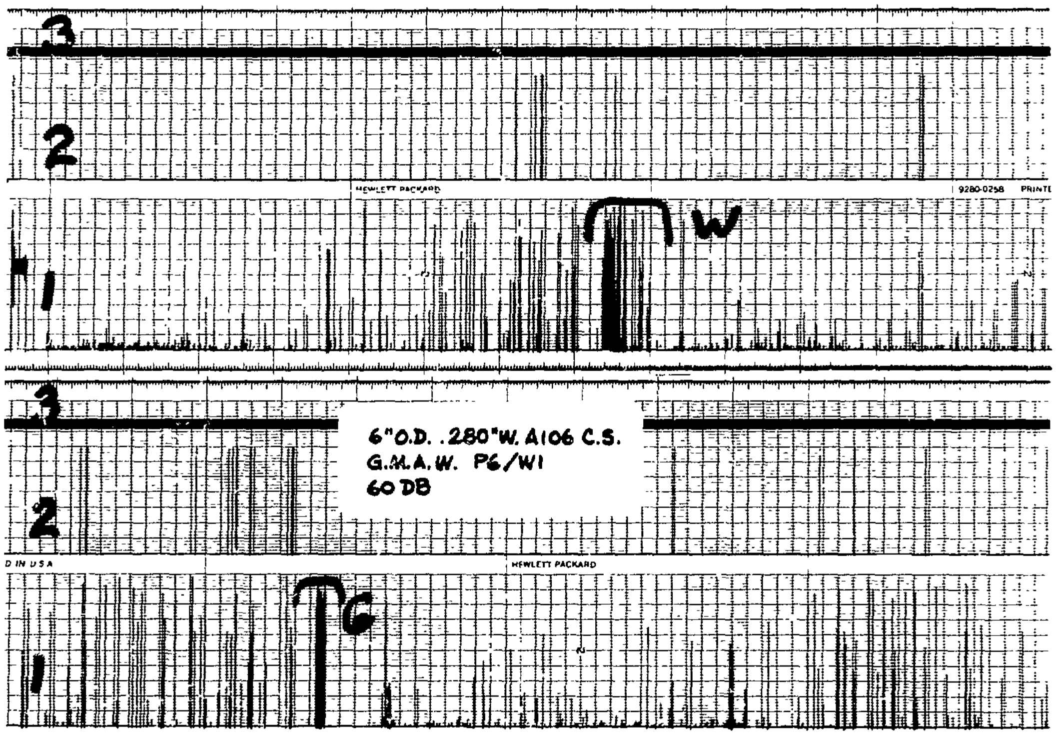

FIGURE 3. ACOUSTIC EMISSION RECORD FOR 152.4 mm O.D. A 106 CARBON STEEL PIPE CALIBRATION TEST WELD

Neither of these disturbances produced an alarm signal in track 3. This example shows how normal production noises can be suppressed in the acoustic emission monitor so as to not produce false alarms.

Artificial flaws were introduced in the calibration test welds by contamination with copper. Frequently, the cracking induced by the copper not only produced easily detectable acoustic emission activity in the pass in which it was introduced but continued to produce activity through several subsequent passes. Figure 4 shows an example of this on 355.6 mm OD carbon steel pipe. Copper was introduced on a GTAW (TIG) root pass and produced some cracking as well as acoustic emission activity. When the automatic submerged arc welding was applied to complete the weld, the copper produced cracks and acoustic emission alarms through 3 of the 5 passes needed to finish the weld. The activity is obvious in both tracks 1 and 2, and the alarms are seen in the brackets in track 3.

The ability of acoustic emission to detect cracks which are difficult, if not impossible, to detect by conventional NDT methods is illustrated in results obtained on a GMAW (MIG) weld on a 152.4 mm stainless steel test weld. Copper was introduced during welding, and acoustic emission alarm was produced. ASME Code radiography performed on the weld failed to detect the crack. Careful laboratory radiography performed later still detected no crack. The acoustic emission record is shown in Figure 5. The quiet nature of 304 stainless steel is readily apparent. Copper was introduced in the later portion of the weld and is shown by a shaded area marked on track 2. The single AE alarm occurs approximately 10 seconds after the introduction of the copper. Metallography confirmed the crack. The metallographic section is shown in Figure 6. Magnification is approximately 6x, and a photographic negative is used to highlight the crack. Two portions of the crack can be seen. The crack was of an interpass type and was in a plane parallel to the weld surface, hence its poor radiographic detectability.

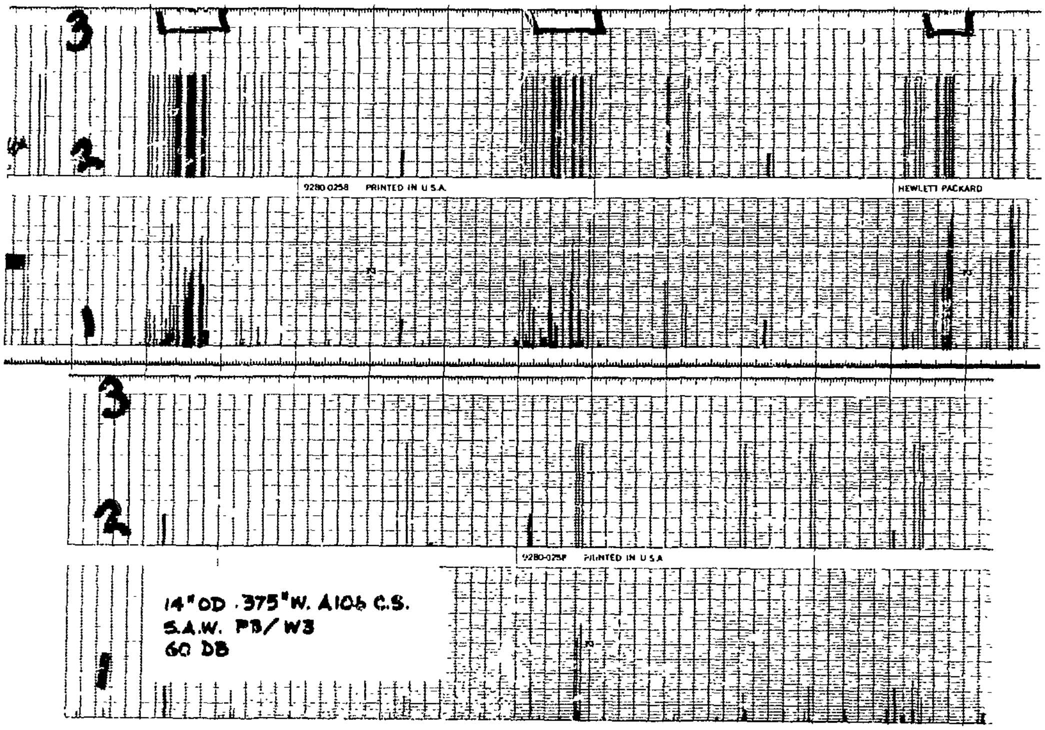

FIGURE 4 ACOUSTIC EMISSION RECORD FOR 355.6 mm OD A106 CARBON STEEL PIPE CALIBRATION TEST WELD

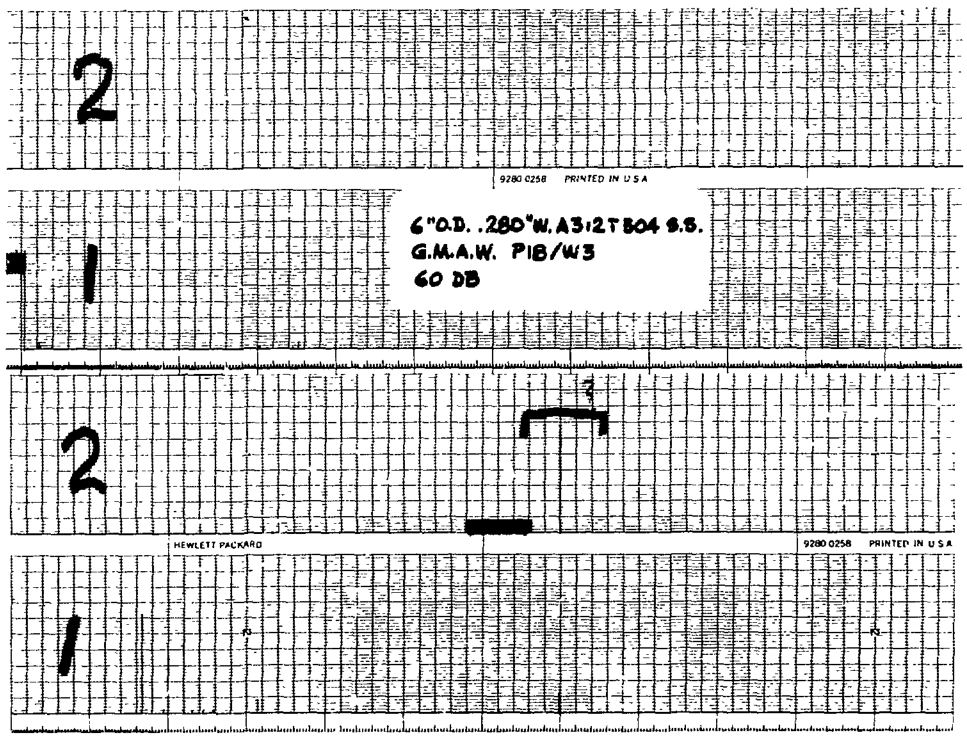

FIGURE 5 ACOUSTIC EMISSION RECORD FOR 152.4 mm OD A312T304 STAINLESS STEEL PIPE CALIBRATION TEST WELD

FIGURE 6 METALLOGRAPHIC CROSS SECTION OF
A 312T304 STAINLESS STEEL PIPE CALIBRATION TEST WELD

In addition to the calibration welds, two weeks of actual nuclear production piping welding was monitored in two separate pipe fabrication shops. A total of eleven acoustic emission indications were produced. All of these correlated with either visual, dye penetrant, or ASME Code radiographic results. Six indications were obtained during a series of GTAW (TIG) repairs on a heavy walled stainless steel section of primary loop piping. The cracks were confirmed by dye penetrant and were eventually ground out and successfully repaired. One indication was produced by small radial cracks found in a GTAW root weld caused by improper arc break off. The cracks were visually confirmed and repaired on the spot by the welder. The remaining four AE indications were all due to slag inclusions which were judged not rejectable by ASME Code radiography. The slag inclusion indications could probably have been eliminated by a slight reduction in the AE monitors gain without any loss of the rejectable indication.

SUMMARY AND CONCLUSIONS

The feasibility of using in-process acoustic emission monitoring to detect flaws in nuclear quality piping welds has been amply demonstrated. Over 300 meters of multi-pass weld was successfully monitored with excellent correlation between acoustic emission and other NDT methods. GARD designed noise suppression, and signal processing techniques have been shown to be quite useful in suppressing the normal background noise of a typical pipe fabrication shop environment. These techniques have been incorporated in a portable, production oriented weld monitor. A photograph of the monitor is shown in Figure 7. The instrument is currently undergoing extensive evaluation in a nuclear pipe fabrication facility as part of a United States Nuclear Regulatory Commission sponsored program. The work reported in this paper was also done under the above referenced program. Current work under USNRC sponsorship continues in the area of in-process reactor pressure vessel weld monitoring.

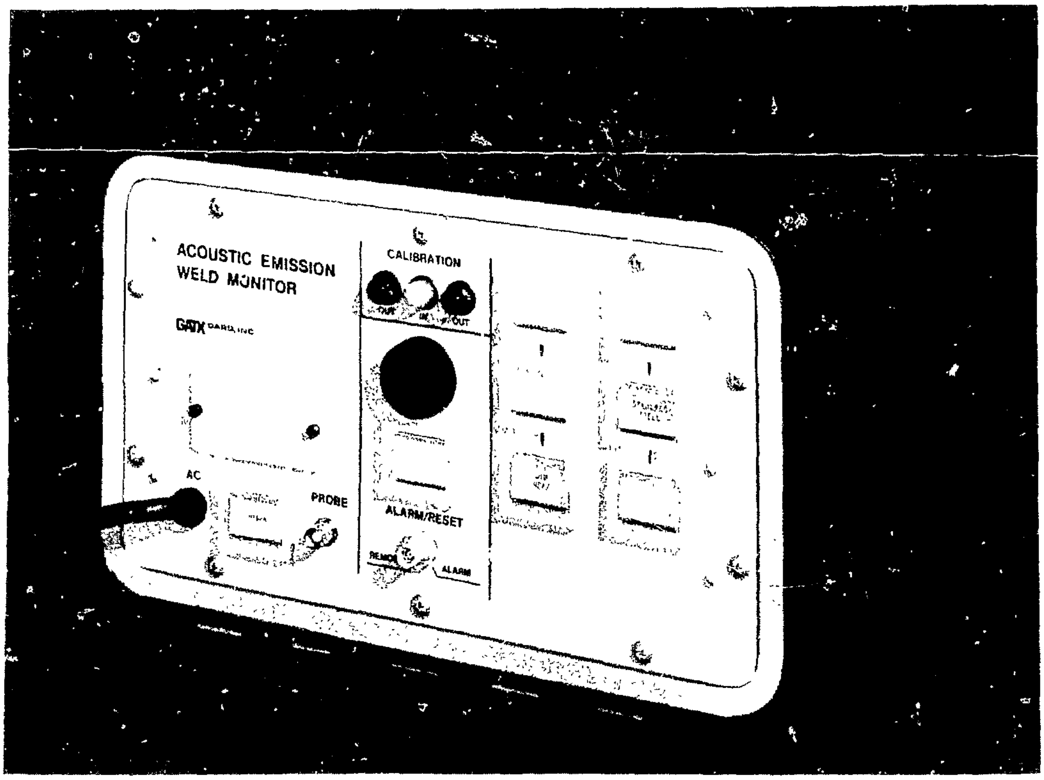

FIGURE 7 PRODUCTION ACOUSTIC EMISSION WELD MONITOR

[illegible]

(1) JOLLY W. D., AN IN SITU WELD DETECT DETECTOR, ACOUSTIC EMISSION, BNWL-817 (1968).

(2) [illegible] K., ACOUSTIC EMISSION AND MICROSCOPIC DEFORMATION, UCLA (1974).