IN8400508

B.A.R.C. -1216

B.A.R.C.-1216

भारत सरकार
GOVERNMENT OF INDIA
परमाणु ऊर्जा आयोग
ATOMIC ENERGY COMMISSION

AN INTRODUCTION TO ACOUSTIC EMISSION TECHNOLOGY FOR IN-PROCESS INSPECTION OF WELDS

by

G. L. Goswami
Radiometallurgy Division

भाभा परमाणु अनुसंधान केन्द्र
BHABHA ATOMIC RESEARCH CENTRE
बंबई, भारत
BOMBAY, INDIA
1983

B.A.R.C.-1216

B.A.R.C.-1216

GOVERNMENT OF INDIA
ATOMIC ENERGY COMMISSION

AN INTRODUCTION TO ACOUSTIC EMISSION TECHNOLOGY FOR IN-PROCESS INSPECTION OF WELDS

by

G.L. Goswami
Radiometallurgy Division

BHABHA ATOMIC RESEARCH CENTRE
Bombay, India
1983

INIS Subject Category : E 17.00

Descriptors

WELDING

WELDED JOINTS

QUALITY CONTROL

DEFECTS

ACOUSTIC MONITORING

ON-LINE SYSTEMS

ACOUSTIC EMISSION TESTING

INSPECTION

CRACKS

REVIEWS

AN INTRODUCTION TO ACOUSTIC EMISSION TECHNOLOGY FOR IN-PROCESS INSPECTION OF WELDS

G.L. Goswami
Radiometallurgy Division
Bhabha Atomic Research Centre
Trombay, Bombay-400085

1. ABSTRACT

Weld quality monitoring, as it stands today, is primarily done by X-ray radiography and ultrasonic testing which is applied after welding is complete. Acoustic Emission Technique (AET) also presents a possible substitute for weld quality monitoring which can be used during welding. Acoustic signals are generated during welding and the sound waves of weld defects are picked up by using AE sensors. These Acoustic waves can be analysed for detecting the weld defects. With the introduction of sophisticated instrumentation in AET, it is possible to carry out the test even in noisy shop floor environments. Large number of reports on the subject of Acoustic Emission in recent years is a clear indication that it is gaining importance in welding industry.

We review the present day status of the Acoustic Emission Technology as an on-line weld quality monitoring technique. This report discusses the technique and system along with the acoustic emission parameters important for weld quality analysis. This also deals with the application of this technique in different welding processes like TIG, resistance, electro slag and submerged arc. It has been reported that monitoring of emission during welding can detect crack formation, crack growth and lack of fusion precisely. Static defects like porosity and inclusion do not generate very strong acoustic signals and are therefore difficult to intercept, but, however, lately it has beendetected successfully.

2. INTRODUCTION TO ACOUSTIC EMISSION TECHNIQUE

Acoustic Emission is an elastic transient wave generated by the rapid release of energy within the material. Elastic waves thus generated can be detected by a sensor attached to the surface of the specimen. A typical acoustic emission signal is shown in Fig. 1. This also lists out the various terms used in Acoustic Emission testing like ringdown count, event, event duration, threshold, noise, rise time etc. The count rate and total counts of emission are most frequently used as measures of Acoustic Emission activities. Amplitude and frequency spectra are sometimes used as supplementary information. By using several sensors it is possible to measure differences between arrival time of wave from single emission and hence to locate the source by triangulation.

An important feature of the Acoustic Emission in general is its irreversibility. If a material is loaded to a given stress level and then unloaded, usually no emissions will be observed upon immediate reloading until the previous load has been exceeded. The Acoustic Emission is capable of detecting growing flaws atleast an order of magnitude smaller than those detectable by other known NDT methods and is capable of locating one or more discontinuities while they are growing. The minimum detectable crack size for ultrasonic, radiography and eddy current methods is about 0.001 inch if a separate set of ideal conditions is met for each technique. Acoustic Emission inspection, though cannot detect static crack, can detect crack growth, of the order of 10^{-12} inches assuming the deformation time to be 20 u Sec. or less. Micro cracks in the size range of 10^{-5} to 10^{-6} inches can be detected as they are formed(1).

Continuous and burst type acoustic emissions are possible depending upon their duration. Continuous type of acoustic emissions is associated with the dislocation movements. Burst type of emissions is of short duration (10 microseconds to a few milliseconds) and is generated by twinning, microyielding and the development of microcracks and macrocracks. It is the burst type of emissions which usually occurs in welding operation. Acoustic Emission Technique can easily be applied during welding to detect discontinuities (weld defects) as they form without interfering with the welding operations. Acoustic waves generated during welding are intercepted by sensors which convert them to electrical pulses which are amplified by pre-amplifier. The amplified signals are filtered for noises of different frequencies and again amplified before feeding to microprocessor for further analysis. Results of these analyses are displayed graphically and can be recorded whenever required. By proper analysis of acoustic waves generated during welding, it seems to be possible to assess the quality of the weld.

Acoustic Emission Technique (AET) presents a possible substitute for weld quality monitoring. A major attribute of applying Acoustic Emission (AE) for in-process monitoring of welds is the ability of the method to provide immediate real time information on weld integrity. However, in comparison, X-ray radiography and ultrasonic testing are applied after welding is over. Moreover, radiographic methods are insensitive to hair line crack lying in a plane perpendicular to the direction of radiation and are relatively slow, since considerable time is required to set up, expose, develop and read photographic film. On the other hand ultrasonic testing is cheaper and in many cases may be performed with greater sensitivity. However, ultrasonic test results are influenced by variables in technique by which the data are acquired. Not infrequently, ultrasonic tests are inapplicable to complex geometries. With the present day electronics in AET, it is not difficult to test the weld in noisy shop floor environments.

Early efforts of AET with different applications were mainly reported by the suppliers of such equipments. However, industrial applications of AET with different welding processes are being tried and results are quite encouraging.

3. ACOUSTIC EMISSION SYSTEM

A typical Acoustic Emission System consists of sensors, preamplifiers, band pass filters, amplifier, graphic display and recorder. Block diagram of Acoustic Emission system for weld defect location is shown in Fig. 2.

3.1 Sensors/Transducers:

Detection of Acoustic Emission is accomplished by the transducer/sensor acting through a couplant. These are, generally, piezoelectric crystals which convert the acoustic signal to an electrical pulse. A typical A.E. sensor is shown in Fig. 3. Various piezoelectric crystals used for this purpose are Quartz, Lithium Sulphate, Barium titanate, Lead Zirconate titanate and Lead metaniobate. Lead zirconate titanate (PZT) is widely used for Acoustic Emission applications because of its excellent high temperature performance and high sensitivity.

The important criteria for selection of the sensors are as follows:

(a) Broad band transducers are essential for frequency analysis with flat frequency response characteristics.

(b) It is advantageous to choose the resonant frequency sensor that will maximise signal-to-noise ratio and yield a sharp (i.e. well-damped) response to the emission of a particular frequency.

In addition to piezoelectric sensors, electromagnetic, capacitive and optical sensors are also being developed for different applications of AET.

3.2 Sensor Coupling Technique:

Location of sensor in AET is not that critical. Since most discontinuities act as point source emitters, acoustic signal travels in spherical wave fronts. Often, a sensor located anywhere on the structure being tested can detect emissions which is in direct contrast to other methods of NDT where prior knowledge of the discontinuity is essential in order to direct a beam of energy through the structure on a path that will properly intersect the discontinuity.

Couplant is used to fill the air gap between sensor shoe and the structure and thereby, couple the AE energy from the structure to the sensor. The characteristics of the couplant should be (i) to wet the test and the sensor shoe; (ii) not to trap the air bubbles; (iii) to be easily removable. High temperature couplants are also available for use during acoustic emission testing of welds. The wave guide which can be defined as a mechanical device for isolating the AE sensor from adverse environment while maintaining the acoustic communication from the structure to the sensor, can also be used during weld monitoring. It is generally used to isolate the sensor from the temperature and radiations, destructive to the sensor, generated during welding.

3.3 Preamplifiers, Filters & Amplifiers:

In the choice of preamplifier, band pass filter and amplifier, the objective is to optimise the signal-to-noise ratio. The amplitude of the emissions generally varies over several orders of magnitude and it is important both to minimise amplifier noise and to ensure rapid recovery of the instrumentation from transient over-loading because Acoustic Emission signals are very transient (0.3 u sec.). The signals as detected are in analog of the true signals, in the sense that they represent transducer response characteristics.

Filters are used essentially to eliminate the background noise and transmit the signal in the desired frequency range. Background machine and personnel noise, with lower cut off frequency approximately in the range of 20 KHZ to 50 KHZ[4] and electrical noise in the range of 1 MHZ or more can be eliminated. Low pass, high pass and band pass filters are available and any one of the above can be chosen depending upon the application and noise level.

3.4 Signal Process Instrumentation:

The conditioned (amplified and filtered) AE signals are processed in order to achieve one or more of the following:

1) Accept AE signals of interest and reject all others.

2) Process the accepted signals and characterise the signals (event, event rate, event duration, ring down count, count rate, peak amplitude, rise time etc.) to determine the type of AE.

3) Location of the source of AE.

Microprocessor-based and computer-based systems are available for signal process instrumentation.

3.5 Data Recording:

There are several methods of generating a record of acoustic emission activity. Fast recording of input data and output data of signal process instrumentation is essential for meaningful conclusion and future records. The following is a list of recording devices most often used.

- X-Y recorder
- Y-T recorder (Strip chart recorder)
- Storage oscilliscope
- Tape recorder
- Computer hard copy unit
- Digital recorder
- Camera

4. ACOUSTIC EMISSION MONITORING

Application of Acoustic emission technique for weld quality monitoring calls for special attention and care. Welding process generally involves application of large amounts of energy causing excessive high temperature. The sensor is placed in direct contact with the port to be monitored (away from the hot zone); usually with an insulating shoe interposed between it and the test part in order to produce positive electrical isolation. The shoe is usually bonded to the piezoelectric sensor, it becoming a part of the sensor body as shown in Fig. 3.

One of the major problems in monitoring the welding process by acoustic emission is the interference of mechanical and electrical noises with the genuine signals. Electrical noise is produced by switching on/off the electrical units, pulse equipments etc. and is a function of instrument shielding and good electrical grounding. Good shielding practice demands that voltage drop caused by current in ground conductor be less than signal voltage. The signal levels detected at the sensors are measured in microvolts and, therefore, a very low impedence ground is needed. Mechanical noises are produced by poor fixturing, slipping of movable parts or otherwise noisy shop floor environments. This requires close cooperation among the acoustic emission test operator, the welders and others in the vicinity of the welding operation.

Apart from usual noise, both electrical and mechanical, noises are also added by high frequency unit during arc welding, slag cracking and flaking of oxide layer during electro-slag welding. Signal from delayed cracking and reheat cracking may also shadow the genuine signal from welding defect when welding operation is continuous. Proper selection of parameters for signal detection and processing is therefore very critical. Some of the important parameters in AET which needs careful consideration are frequency, threshold amplitude, gain and output characterisation of signal. These are discussed below separately.

4.1 Resonance Frequency of the Sensor:

Proper choice of resonance frequency of the sensor with appropriate filter for the Acoustic Emission monitoring can eliminate much of the background noise. Mechanically induced noises have very little energy above 100 KHZ and they peak in the range of 20 KHZ to 50 KHZ. Electrical noise pick up is higher with higher operating frequency. Much of this kind of noise can be suppressed by filtering out acoustic above 1 MHZ frequency. And therefore, filtering of the acoustic signal below 100 KHZ and above 1 MHZ will eliminate much of the mechanically and electrically induced noise. Moreover, sound attenuation in most of the engineering materials is low in this range of 100 KHZ to 1 MHZ and therefore, sensors can be placed at some distance away from the flaw weld location without much loss of signal strength.

4.2 Threshold Amplitude:

Much of the background noise can also be eliminated by setting the proper threshold, i.e., detecting the Acoustic Emission signals above the specified level. However, background noise is never constant and some of the background noise above fixed threshold during the test can be mistaken for genuine Acoustic Emission signal. In order to avoid this fluctuating background noise, an idea of floating threshold has been mooted which means threshold level changes according to the background noise(2). This therefore separates the genuine acoustic emission signal from background noise and process further.

4.3 Gain

Gain is a general term used to denote the amplification of the signal during its conditioning. It is the ratio of the output of the transducer after conditioning to the input of the signal. It is usually expressed in decibel, i.e., log of the ratio of voltages as defined below:(3)

$$dB = 20 \log_{10} \frac{V_2}{V_1}$$

Judicious choice of gain should be made in order to amplify the signal high enough in amplitude and low enough in impedence so that signal can be handled by the usual electro signal transfer techniques.

4.4 Characterisation of A.E. Signal:

Acoustic signals generated during welding can be resolved for the events, event rate, ring down count, count rate, peak amplitude, rise time etc. With the present day electronics it is possible to process the signal within the set range of the above mentioned parameters, thus ignoring the signals not of interest, e.g. mechanical noise sources tend to have slower rise time to a given amplitude then crack growth emission and can be ignored by specifying proper range of rise time or emissions from micro crack initiation showed relatively longer event duration (compared to their peak amplitude) than emission from later macrocrack propagation and can be separately analysed by specifying proper range of event duration(4). Thus, proper specification of input parameters and range of output parameters would lead to converge on the acoustic signal needed for identification of the quality of the weld.

Application of AET to Welding Process:

Acoustic Emission Technique has been applied to monitor the quality of weld made by different welding processes. Different welding processes produce their characteristics, weld defects and accordingly acoustic waves are generated. Different welding processes also produce typical problems to AE monitoring and these have been discussed below.

5. DIFFERENT WELDING METHODS AS MONITORED BY AET

5.1 TIG Welding:

It is an arc welding process in which the heat is produced between a non-consumable electrode (Tungsten) and the work metal. The electrode, the weld puddle and the adjacent heated areas of the work piece are protected from atmospheric contamination by a gaseous shield. Defects typical of this process are cracking or microfissuring, lack of penetration, porosity and pin holes.

Weld cracking has been successfully monitored using Acoustic Emission Technique in TIG welding by W.D. Jolly(5,6). The weld cracking has been intentionally induced by introducing Titanium or Tantalum into the 13 mm thick stainless steel weld joint. The welds, 50 mm long, were made on several passes on the base plate and were contaminated with Titanium or Tantalum in the third pass which resulted in weld cracking. The correlation between the weld quality and Acoustic Emission, as recorded by the author, is shown in Fig. 4. It is evident that there is a sudden increase in the acoustic activity in the third pass when Titanium or Tantalum is added for producing weld cracking.

Crack length can also be related to the total acoustic events. C.K. Day(7) has observed a trend of increasing the Acoustic Emission events with higher relative crack length, measured by metallography. Fig. 5 shows relative cracklength versus total acoustic emissions.

In nuclear industry, TIG welding has been universally accepted as a standard process for manufacture of nuclear fuel rods. Weld signature has been obtained by D.M. Romvell(8) during Acoustic Emission monitoring of FFTF Reactor fuel pin end closure welds. Fig. 6 shows the Acoustic Emission counts as recorded by him during welding and cooling of the bottom-end-cap weld for a type 316 stainless steel reactor fuel pin. He observed that the weld with high Acoustic Emission activity is having microcracks and fissures and is in line with the observation made by C.K. Day.

Acoustic Emission Technique can also be used for process control in TIG welding. An example of a defective weld produced due to insufficient weld current is shown in Fig. 7.(9)

Detection of cracking in welds by acoustic emission technique is possible with a high degree of confidence. Even detection of the lack of penetration seems to be possible by this technique. However, defects like porosity or pin holes which produce relatively weak acoustic signals may be difficult to detect. Though it has been reported that gross porosity formation produces high acoustic activity, it is likely that cracking which accompanied the porosity might have been source of high emission. Moreover, acoustic emission technique, at present, may not be able to differentiate between two type of defects formed simultaneously during welding.

4.2 Submerged arc welding:

Submerged arc welding is an arc welding process in which the heat is generated by an arc (or arcs) developed between a bare metal consumable electrode or an electro granular and fusible flux which blankets the molten weld metal and the base metal near the joint.

In this type of weld one of the major problems is the inclusion of slag. Although the weld itself, during submerged arc welding, is protected from the atmosphere by applying a granulated silicate flux that melts in the arc to form a glassy cover over the weld head, the slag inclusion will occur when a piece of this cover becomes trapped beneath the weld bead.

W.D. Jolly(6) has reported that the Acoustic Emission rate during submerged arc welding correlates well with the conformation of the bead surface as shown in Fig. 8. The Acoustic Emission rate increases drastically as the bead conformation changes progressively from a normal bead to what is called a roped bead. The normal bead presents a smooth surface that prevents slag from being trapped. The rope bead, as the name implied, has edge and pockets along its side which can trap slag on the next weld pass and thus causes a slag inclusion.

The correlations found stem from the fact that the glassy cover over a normal bead lifts away smoothly as it cools and solidifies whereas glassy cover from poorly formed bead with partially trapped slag fractures extensively as it separates from the weld bead surfaces. The ability of Acoustic Emission Technique to detect variations in weld bead quality and to locate the defects on the weld surface can reduce the rework-time from days to minutes.

Kenneth R. Notvest(10) has recorded acoustic emission signature corresponding to the weld area containing pin holes and A.E. activity from this weld is greater than normal due to trapped slag and fissuring caused by a loose fitting backing strip. High acoustic activity is believed to be due to fissuring from the pinholes as detection of pinholes and porosity with AE is normally very difficult.

Submerged arc welding is a versatile process, which is used for continuous welding running upto a few meters. Fig. 9 shows a typical arrangement for Acoustic Emission monitoring(11) during continuous welding where moving sensor configuration with sensor position fixed relative to meld head is shown. It shows how moving Acoustic Emission Technique equipment can be used for monitoring whole length of the continuous welding.

In multipass welding, it is important to have a multi channel processing system with multi sensor so that defect location can easily be computed otherwise misleading conclusion may be drawn. For example, stress rupture crack occured during fifth pass may have been considered to be in the fifth pass but actually crack might be in the weld root.

4.3 Electroslag welding:

Electroslag welding is a process in which heat from a layer of molten flux (slag) melts a consumable electrode and the surface ofthe base metal to produce a weld puddle. Filler metal (the electrode) is fed into a molten flux pool contained in a packet formed by copper shoes or dams that bridge the gap between members being joined. The process utilizes the electrical resisting of the molten flux to produce continuously the heat needed to melt the filter metal and adjacent base metal.

The major problem in Acoustic Emission Technique monitoring during Electroslag welding arises from the electrical noise from large welding current and mechanical noise of flux cracking and sputtering, which interfere with the genuine acoustic emission signals. In order to differentiate between genuine acoustic emission signals from the signals due to slag cracking, two different resonant frequency sensors could be employed. Resonance frequency of these sensors should be chosen so as to differentiate the signals. Results published by M. Onoe(12) indicates that dominant frequency of the signal generated from slag cracking is lower (≅ 50 KHZ) than from the weld cracking (≅ 1 MHZ).

4.4 Resistance welding:

Resistance welding is the process where heat is generated by resistance to the flow of electric current through work pieces that are held together under force by electrodes. Statistical quality control methods are used for monitoring the resistance weld as there is no other NDT method available. This explains why most of the Acoustic Emission Technique work in welding has been devoted for this type of welding. It has qualified itself to be a good NDT method for on-line monitoring of the resistance welding.

The resistance spot welding can be monitored and controlled with ease by Acoustic Emission Technique. The making of resistance weld generally consist of: (a) Set down of electrodes, (b) Squeeze, (c) Current flow, (d) Hold time, and (e) Electrode lift-off.

Typical Acoustic Emission signals observed during resistance spot welding are shown in Fig. 10(13). Electrode and surface condition of the component give rise to some of the acoustic noise during the set down and squeeze operation. The large signals of short durations at the start of the current flow are due to the initial resistance and cleanliness of the parts. During the stage of current flow, Acoustic Emission results from plastic deformation, friction, melting and flashing (expulsion) of the molten metal. The signals associated with the expulsion are generally of lower amplitude than the rest of the Acoustic Emission associated with the nugget formation. When current flow ceases, some materials emit appreciable Acoustic Emission signals during transformation and they can be related to the size of the muggest and presence of the inclusions. Fig. 11(14) shows Acoustic Emission response as related to the nuggest diameter in 6061 Aluminium spot welds. It is clear from the figure that as nuggest diameter increases emission pulses per weld increases.

Strength of resistance welds has been reported (1,16) in correlation with Acoustic Emission counts. The approach in monitoring resistance welding is somewhat different. The amount of Acoustic Emission detected appears to bear direct relationship with the strength of the resistance welds whereas in other welding processes it generally means defective weld (5, 6, 12, 15). This could probably be due to the hot working which is associated with the resistance welding. It has been reported that (17) tensile shear strength of a resistance weld is proportional to the total count of acoustic emission measured during the welding cycle. Relationship of tensile shear strength with total acoustic emission count by varying the current level in both single and double projection welds of zircaloy specimens is given in Figs. 12 and 13 respectively. The cleanliness of zircaloy specimen surfaces before welding has influence on the weld strength and the total acoustic emission count mainly because of excess oxide formation. Although there was evidence of interference between two sensors in double projection welding, particularly at high currents, the total Acoustic Emission count from each sensor was a measure of the weld strength.

Acoustic Emission monitoring[18] has also been done during post weld qualification of Aluminium to copper flash butt welding.

Resistance welding is very commonly used during fabrication of fuel rods for PWR, BWR and PHWR. Even spot welding of spacer wire in PHWR fuel rods is done by resistance welding. All these welds are at present, monitored by statistical quality control and no NDT method exists today for the same. I feel that Acoustic Emission Technique could be developed for monitoring the weld wuality in nuclear fuel rod production.

4.5 Special Welding Technique:

Very little work has been reported of having monitored special welding techniques like electron beam welding and laser beam welding using Acoustic Emission Technique. It may be because these techniques are known to produce defect-free welds. Since one can control the energy of beams and focus them very precisely on to a very small area thereby reducing the possibility of the formation of a weld defect. But still we see no reason, with the development of finer electronic circuitry, why Acoustic Emission Technique cannot be applied for the monitoring of these special welding techniques.

5.0 SUMMARY

It has been demonstrated beyond reasonable doubt that Acoustic Emission Technique can be used as an on-line weld quality monitoring method. It is possible to intercept weld defects like lack of penetration, weld cracking, delayed cracking and inclusions quite precisely as large energy changes take place during their formation. However still there are differences of opinion in the detection of pinholes and porosity as energy released is quite small. But with the advancement of electronic circuitry it should be possible to detect even such defects which release low signal.

This technique requires a lot of initial experimentation with a particular weld application for driving out the optimum acoustic parameters. But having once established the proper parameters, this technique is more useful in repetitive production welding jobs.

In order to use the Acoustic Emission Technique more effectively, techniques for producing welds with known defects of controllable size are being developed (19) which can be used for calibration or as standards. Through Acoustic Emission Technique has not become popular in India, in due course it will find its use in welding industry, as a large number of institutions have already started research in this field.

6.0 ACKNOWLEDGEMENTS

The author is very grateful to Shri P.R. Roy, Head, Metallurgy Group for his keen interest and encouragement and also to Shri R.P. Menon for his help in the preparation of this report.

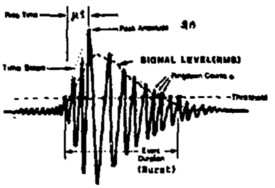
7. REFERENCES

1. Metals hand book, vol. 11, "AE Inspection" ASM, 8th Edition, p 234-243.
2. Data sheet '3000', '201', '204 A', Acoustic Emission System, AET Corporation, USA.
3. Acoustic Emission Seminar, Revised March 1982, AET Corporation, USA.
4. Acoustic Emission Trends, Vol. 3, No. 1.
5. W.D. Jolly, "AE exposes cracks during welding process", The Welding Journal, Vol. 48, 1969.
6. W.D. Jolly, "The application of AE to in-process inspection of welds" Materials evaluation, June 1970, pp 135.
7. C.K. Day, "An investigation of AE from defect deformation in stainless steel coupons", BNWL-902.
8. D.M. Romvell, "The A.E. Monitoring of FFTF reactor fuel pin and closure welds", Materials evaluation, Dec. 1972.
9. A.A. Pollock, "Trouble talks acoustic emission", Machine design, April 8, 1976.
10. Kenneth R. Notvest, "On line detection of weld defects with AE", distributed by AET Corporation, California.
11. ASTM STANDARDS "AE Monitoring during continuous welding", E-749-80, p.728.
12. M. Onnoe - Acoustic emission research in Japan for flow detection in weld.
13. Prabhakar - Indian Non-destructive inspection journal, Oct. 1980.
14. G. Youngman - "AE feed back control of resistance spot welding" International Conference of AE, held in Anaheim California, 1979.
15. W.D. Jolly - "The use of AE as a weld quality monitor", BNWL-SA-2727 Pacific Northwest laboratory, Richland, Washington.
16. Philip H. Hulton, "Flow detection by AE", BNWL, Pacific Northwest Laboratory.
17. International Metal reviews, 249, 1980.
18. Robert B. Steel and Corl C. Popadick, "NDT of Al-Cu using AE techniques" Materials evaluation, Vol. 34, No. 3.
19. HUANG C.F - NUNG K.S. "Acoustic emission analysis of the flows during welding", Third Pan Pacific Conference for Non-destructive testing, Tokyo, Japan, Nov.20-21, 1980.

TABLE 1 (Ref: 23)

AE System Gain range for different welding methods

S.No.	Welding Method	AE system gain range in 'dB'
1.	Submerged Arc (Single or Tandem wire 800-1000 A)	35 - 45
2.	Submerged Arc (Single wire 400-500 A)	45- 55
3.	Submerged Arc (Single wire 200-400 A)	55 - 65
4.	Gas shield metal arc (MIG or short arc 150-400 A)	50 - 70
5.	TIG, 75-250 A	60 - 80



o - Threshold Crossings

- First threshold crossing of a burst = event
- All threshold crossings of a burst = Ringdown Counts.

AE Characteristics:

- Event
- Ringdown Count (RDC)
- Peak Amplitude
- Rise Time = time of first threshold crossing to peak amp.
- Event Duration = time from first to last threshold crossing.
- Signal Level - (RMS Approx.)
- Slope
- Frequency (not shown)

Fig. 1 - A typical acoustic emission signal.

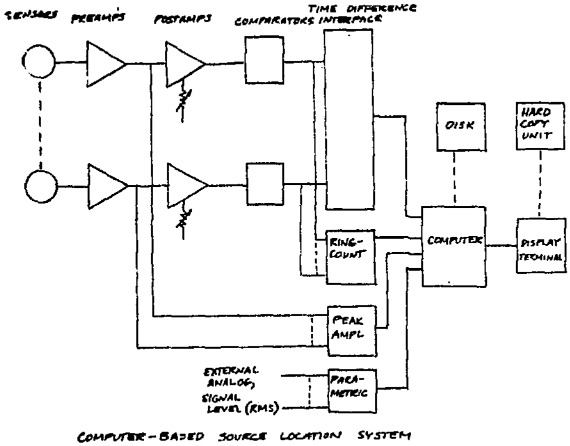


Fig. 2 - Block diagram of acoustic emission system.

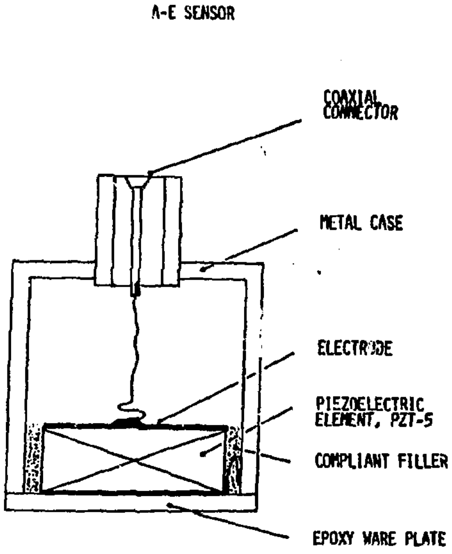


Fig. 3 - A typical acoustic emission sensor.

Fig. 4 - Correlation between acoustic emission and weld quality.

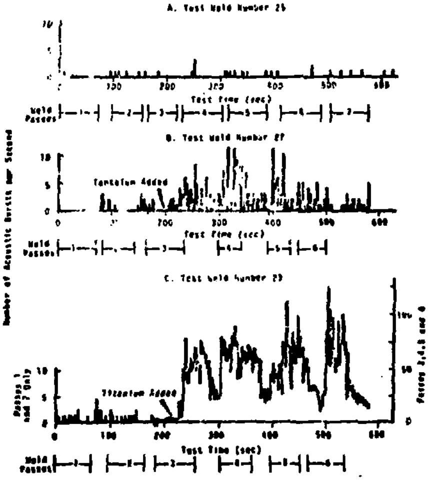


FIGURE 10: Acoustic Emission from Three Welds of Different Quality. Total Relative Crack Lengths from Three Metallographic Sections of Each Weld Are: A. Weld No. 25, [illegible]; B. Weld No. 27, [illegible]; C. Weld No. 23, [illegible]. (See Figure 11 for Photomicrographs.)

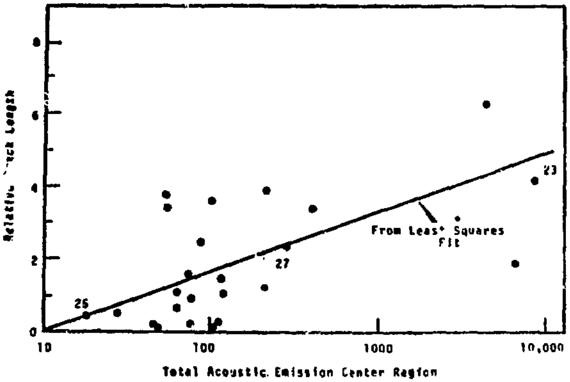


FIGURE 5. Acoustic Emission Versus Crack Length (as Measured from Three Metallographic Sections Each) for the Center Region of 26 Welds. (The Numbered Welds Correspond to those Samples for Which Data Are Shown in Figure 10 and 11.)

21

BNWL-902

Fig. 5 - **Acoustic emission versus crack length.**

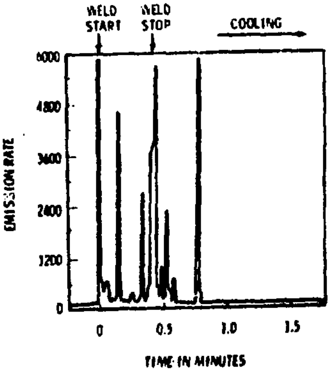
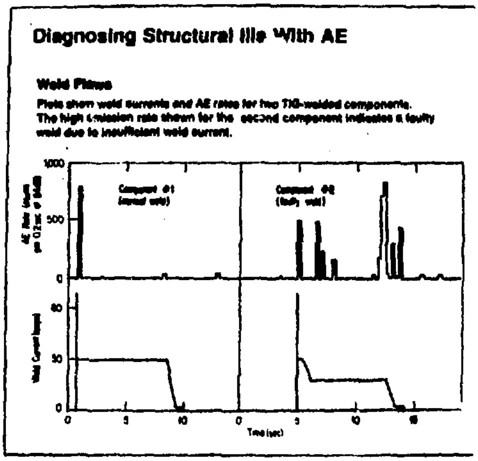


Fig. 6—Emission rate and photomicrographs from sample weld R3-9.

Fig. 6 - **Acoustic emission counts recorded reactor fuel pin weld.**



Diagnosing Structural Ills With AE

Weld Flaws

Plots show weld currents and AE rates for two TIG-welded components. The high emission rate shown for the second component indicates a faulty weld due to insufficient weld current.

Fig. 7 - Weld currents and AE rates for TIG welded components.

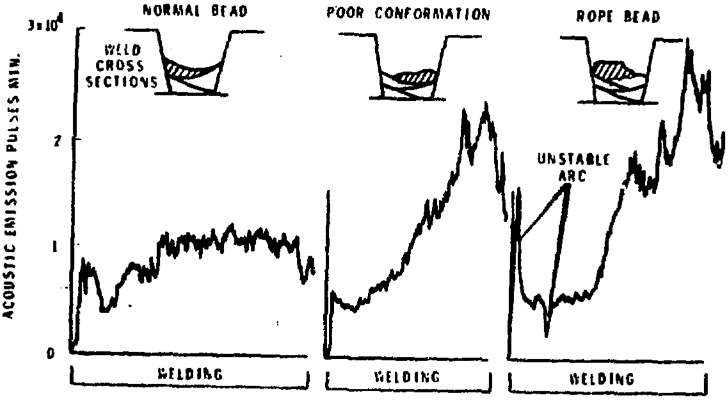


Fig. 8 - Acoustic emission during submerged arc welding.

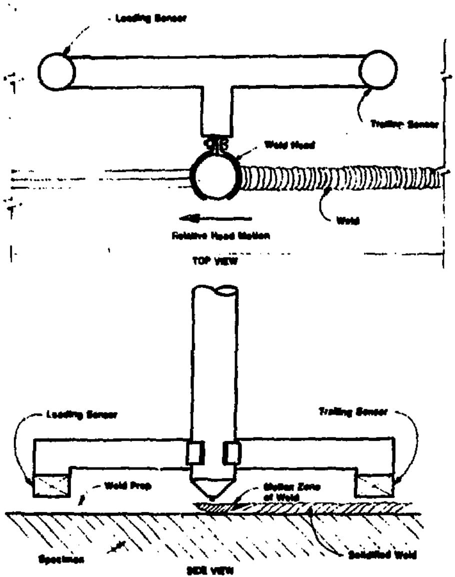


FIG. 9 Moving Sensor Configuration with Sensor Position Fixed Relative to Weld Head

Fig. 9 - A typical arrangement for AE monitoring during continuous welding.

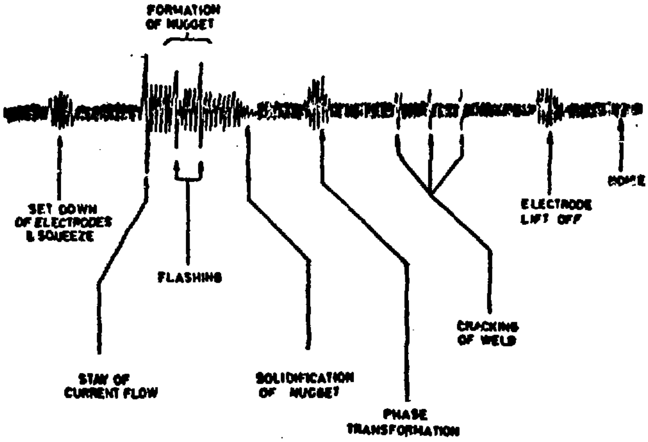


Fig.10 TYPICAL AE SIGNAL FROM RESISTANCE SPOT WELD

Fig. 10 - Typical acoustic emission signals observed during resistance spot welding.

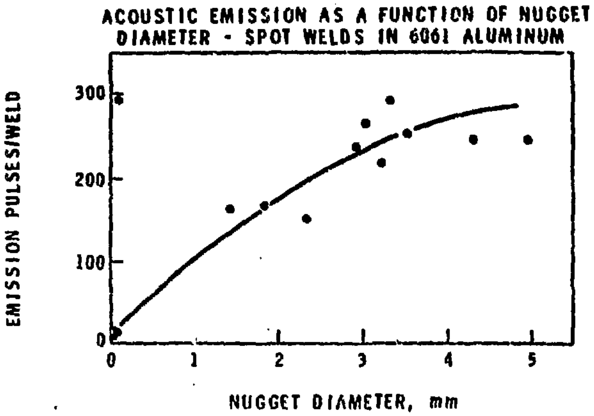


FIGURE 11. Acoustic Emission Response Related to Nugget Diameter in Spot Welds.

Fig. 11 - Acoustic emission response related to nugget diameter in spot welds.

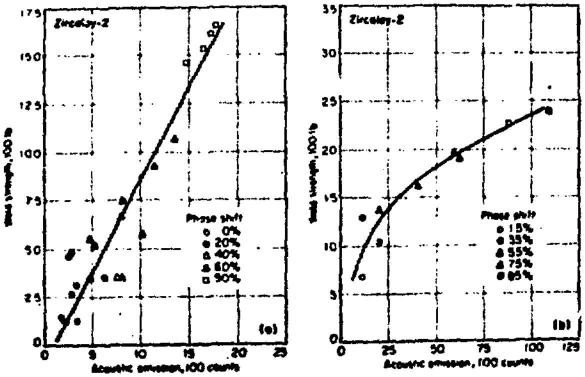
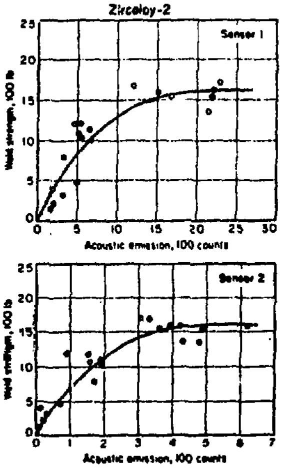


Fig. 12: Relation of tensile-shear weld strength and total acoustic-emission count from single-projection welds in Zircaloy-2 specimens (see Fig. 9), as a function of welding-current level (phase shift). Data in each curve reflect differences in surface conditions of (a) as-received prewelded specimens and (b) cleaned prewelded specimens.

Fig. 12 - Tensile shear stress as related to total AE count for single projection weld.



Data points in each chart were obtained with use of single-impulse single-cycle current and a phase shift from 10 to 90%.

Fig. 13. Relation of tensile-shear strength of double-projection welds in Zircaloy-2 specimens (see Fig. 9) and total emission count, as a function of welding-current level

Fig. 13 - Weld strength related to total AE count of double projection weld for different frequency sensors.