A study of Corrosion Detection Using Acoustics Emission Testing

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Abstract

This paper presents a corrosion detection techniques of storage tank using Acoustics Emission Testing (AET) based on time domain signal parameters. The AE features were used to study about the characteristics of corrosion activities that related with mechanism of active corrosion such as amplitude, hits, duration time, rise time and count. These parameters can be used to identify and to separate a group of AE signal. In this study, the signals were acquired data from the storage tank in laboratory. A rust corrosion was used to simulate various sizes such as 5 in.^{2} and 2 in.^{2}. The sample plates of corrosion were dropped into a storage tank and hold in storage tank more than 8 weeks. The location of simulated corrosion can be detected on the bottom tank location. The AE signal pattern can be used to monitor and to predict the tank floor condition using the acoustics emission testing. This result must compare the result with other methods of nondestructive testing such as MFL and UT to verify location of corrosion on the bottom plate of storage tank.

***Keywords**:* acoustics emission testing, corrosion detection, storage tank

1. Introduction

Corrosion is considered to be one of the major causes for failure of any equipment made from metal. Understanding of corrosion mechanisms was required in order to make corrosion protection. A previous works mainly interested in corrosion protection, however there are a few works those studied on corrosion detection. There are numerous methods to determine the severity of corrosion that occur on damage metal parts. However, In case of storage tank, the shutting down process must require during the examination and data acquisition testing.

In addition, the source location of a structural deterioration and corroding damage is usually consideration such as a bottom flat storage tank. The non-destructive testing in real-time has been required for this type of work. Therefore, Acoustic Emission Testing is interested method for this present work [1]. The condition monitoring is required for tank inspection by owners because they need the result of the corrosion condition in order to plan in preventive maintenance programs.

The corrosion detection has been studied by AE technique applied in various types of corrosion which were uniform corrosion, pitting, crevice, stress corrosion cracking, and abrasion corrosion. AE have been implemented in active corrosion field such as stress corrosion cracking [2], abrasion corrosion, and erosion corrosion [3]. These types of corrosion were influenced by external force or velocity of fluid. The acoustic wave owing to these activities has larger magnitude than that of corrosion process and ease to find the relationship between the corrosion rate and AE parameters [4]. The previous works showed the similar conclusion that AE technique was efficiency for corrosion monitoring. However, the main argument is the source identification of acoustic wave. Mansfield and Stocker found that AE count number related to corrosion rate in various corrosive conditions and showed that the AE sources from the metal are corrode activity and the hydrogen bubble occurrence on electrode [5]. The frequency analyzes of AE signals in abrasion corrosion process was studied and the result showed the sources of AE were impact of glass bead and gas bubble.

2. Acoustics Emission Testing (AET)

Nondestructive Testing can be defined as the development and application of methods to examine materials or components in ways that do not impair future usefulness and serviceability, in order to detect, locate, measure and evaluate flaws; to assess integrity, properties and composition; and to measure geometric characteristic. Acoustic Emission is a powerful method for non-destructive testing and material evaluation in many engineering fields. AE signal can be detected dislocation of microscopic movement and geometric discontinuities. AE is a class of phenomena whereby transient stress or displacement waves are generated by the rapid release of energy from defective source within a material, or the transient wave [6].

The parameters commonly can be used to predict severity in the corrosion process that are AE ring down count, AE HIT, AE Event, AE Amplitude, AE Energy and AE RMS. An AE Burst signal, the typical AE signal from the corrosion process, is shown in fig. 1 and can be describes by these parameters as follows. The ring down count is the number of times a signal exceeds a pre-set threshold. This is a simple measure of the signal size, since larger signals typical give more counts. Electronically this was the first to come into widespread use. By summing the counts from all detected emissions, one has a convenient measurement of the total emission from the specimen or examines. The number of counts (N) can be calculated by equation (1) below. [1], [7]

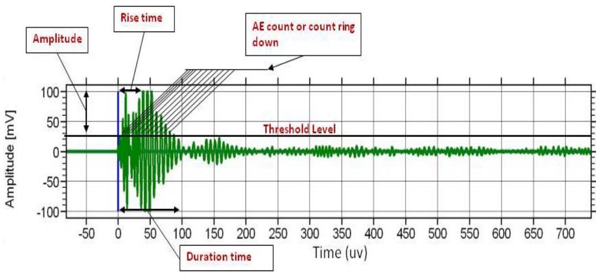

Fig.1 the sample AE signal of Transient Wave

$$N = \frac{\omega}{2\pi B} \ln \frac{V_0}{V_t} \qquad (1)$$

Where:

ω = frequency response

B = decay constant (greater than 0)

V_0 = initial signal amplitude

V_t = threshold voltage of counter

AE RMS is the root mean squared value of the input signal. Since acoustic emission activity is attributed to the rapid release of energy in a material, the energy content of the acoustic emission signal can be related to this energy release. AE RMS can be defined as equation (2)

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^{\tau} V^2(t)\,dt} \qquad (2)$$

Where:

$V(t)$ = signal voltage function

T = threshold of time

AE HIT is the detection and measurement of an AE signal on a channel

AE Event is an occurrence of a local material change or mechanical action resulting in acoustic emission. AE Energy is the energy contained in an acoustic emission signal, which is evaluated as the integral of the volt of the squared function over time. AE Rise time is the time interval between the first threshold crossing and the maximum amplitude of the burst signal. AE duration time is the time interval between the first and the last threshold crossing of the burst signal [1]. These parameters are can be used to classify the signal pattern. For example, long duration events in composites are a valuable indication of delimitation. Signals from electromagnetic interference typically have every short duration time so the duration parameter can be used to filter them out. In this section, duration time will be used to divide the AE source from pitting corrosion into two groups.

3. Corrosion Process

Corrosion is the degradation process of the material into its constituent atoms due to chemical reactions with its ambient environment. The type of corrosion mechanism and its rate of attack depend on surrounding environment such as air, soil, water and humidity that the corrosion takes place. Corrosion returns the metal to its combined state in chemical compounds. These compounds are similar to the minerals which produce the extracted metals. Thus, corrosion has been called extractive metallurgy in reverse and all aqueous corrosion reactions are considered to be electrochemical. Most reactions involve water in either liquid or condensed vapor forms. The reaction that produces corrosion is depicted in figure 2. The anodic reaction is the dissolution of metallic ions (where M indicates the metal) through the passive film, and the cathode reaction involves dissolved oxygen. At the anode pole, the oxidation reaction can be expresses by

$$M \rightarrow M^{2+} + 2e^-$$

(M indicates the metal) and at the cathode pole, the reduction reaction can be present

$$H^+ \rightarrow \frac{1}{2}H_2 - e^-$$

$$2H^+\frac{1}{2}O_2 \rightarrow H_2O - 2e^-$$

Dissolved oxygen reacts with hydrogen atoms adsorbed at random on the iron surface, independent of the presence or absence of impurities in the metal. The oxidation reaction proceeds as rapidly as oxygen reaches the metal surface. Using the reaction $H_2O \rightarrow H^+ + OH^-$ obtained [8].

$$M + H_2O + \frac{1}{2}O_2 \rightarrow M(OH)_2$$

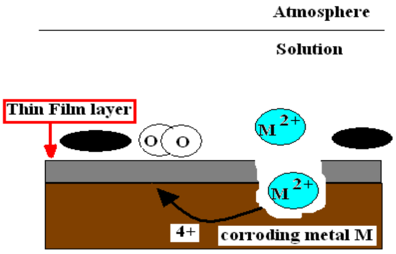

Fig.2. Corrosion mechanism

Since various AE signals are generated throughout the corrosion process, AE activity from corrosion sources was reported with many assumptions such as hydrogen bubble nucleation, evolution of hydrogen near pits, damage of material in pitting corrosion mechanism [9]. The detected AE parameters of corrosion were analyzed using several relations and the AE signals can be divided the groups of signals generated from corrosion and from non-corrosion, such as hydrogen bubbles, water drop and leak event.

4. Experiment

The data acquisition was shown in figure 3 as the procedure of data acquisition system. The data acquisition procedure combined three main steps. There are the data acquisition testing, the signal processing, the evaluation and interpretation. Then, the tanks were prepared to immerse the different plate of rust corrosion at tank bottom as shown in figure 4. The sensor was attached on the tank shell using the magnetic clamp. The first row sensor was high of 10 cm from the tank bottom. The second row sensor was high of 30 cm. from the first row as guard sensor. The sensor has frequency range of 30 kHz to detect the emission corrosion signal [5]. The iron plates had real rust corrosion and were cut out 2 samples with various sizes iron plates of 5 inch^2 and 2 inch^2. as shown in figure 6. The Iron plate had material components which inspected by the positive material identification (PMI) tools using to identify the component of iron plate.

$$Fe = 99.49\%\ , \pm 2\sigma = 0.43\%$$
$$Mn = 0.339\%\ , \pm 2\sigma = 0.11\%$$
$$Nb = 0.057\%\ , \pm 2\sigma = 0.028\%$$
$$Pb = 0.039\%\ , \pm 2\sigma = 0.018\%$$

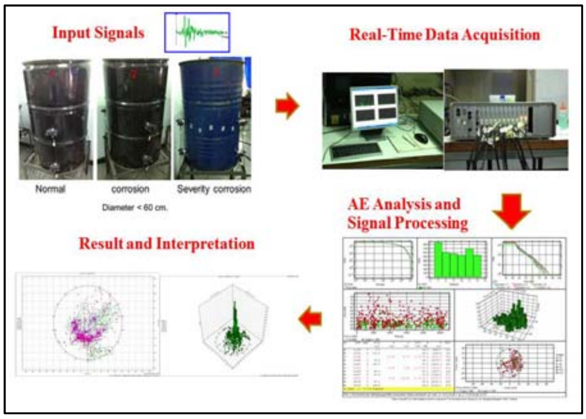

Fig. 3 The Data Acquisition Procedure

Tank No.1 Tank No.2 Tank No. 3

Fig. 4 Sensor setup

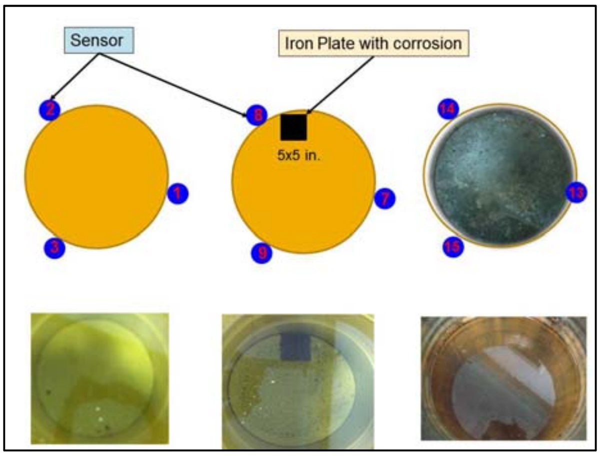

Fig. 5 illustrates a bottom tank with 5 inch^2 corrosion plate.

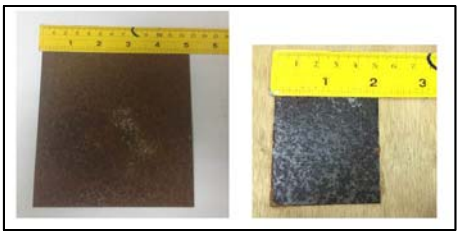

Fig. 6 The iron plate corrosion

The flat plate corrosion with various sizes was soaked on bottom tank in order to simulate the corrosion activity during testing and hold on the iron plate at a bottom tank of 8 weeks before the AE signals were acquired all of testing conditions.

The testing conditions were acquired 2 hours in each condition. The transient wave should generate signals when it had corrosion mechanism and when corrosion process activates an ion process transferring between water and iron plate. In this study, the AE signals were acquired with simultaneous sampling rate of 40 MHz/Channel and number of sample of 8196 sample/Sec with continuous mode until 2 hours per case study The DAQ card was used acquisition system by Vallen system GmbH AMSY-5.

The AE signals were acquired by iron corrosion flat plate that was soaked on a tank bottom in every condition testing. The AE signal can be used to calculate for the source location that were appear from the corrosion activity on the tank bottom by planar source location equation as described below.

$$r_1 - R = (t_2 - t_1)\bullet c = \Delta t_1 \bullet c \tag{3}$$

$$r_2 - R = (t_3 - t_1)\bullet c = \Delta t_2 \bullet c \tag{4}$$

$$R = \frac{1}{2}\left(\frac{D_1^2 - \Delta t_1^2 \bullet c^2}{\Delta t_1 \bullet c + D_1 \cos(\theta - \theta_1)}\right) \tag{5}$$

$$R = \frac{1}{2}\left(\frac{D_2^2 - \Delta t_2^2 \bullet c^2}{\Delta t_2 \bullet c + D_2 \cos(\theta_3 - \theta)}\right) \tag{6}$$

The concept of source location is calculated by time cross correlation principle of each channel. The different of time each channel was defined as AE Hit signal and the AE event was calculated when at less three channel can detect the source of defect within time-recording window setting as the same time of each channel. The AE event was calculated to plot on the graph as shown in figure 8.

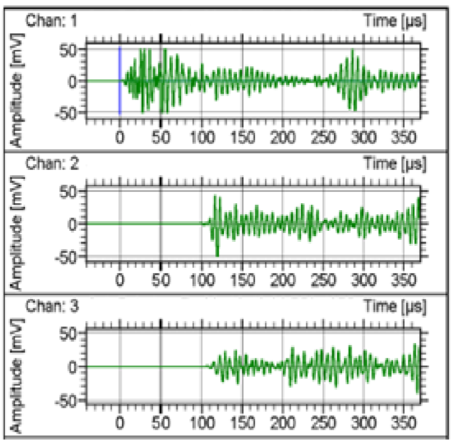

Fig. 7 Time domain Signal of each channel

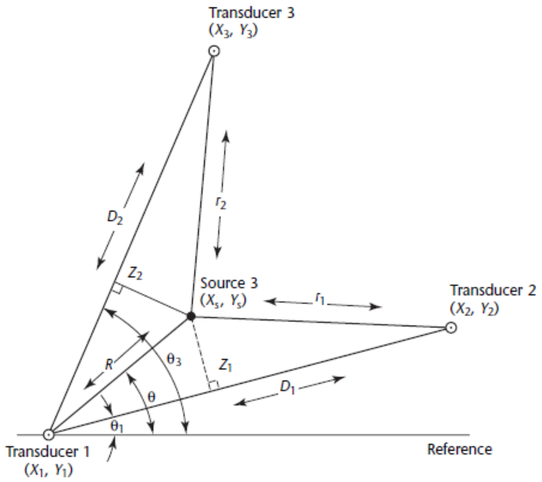

Fig. 8 Source location using an equilateral triangular array [1, 10]

Where

D = Distance (meter) between transducer

R = Radius (meter) from transducer to source

r_1 = Radius (meter) from transducer to source

Z = distance (meter) transducer plane to source

X_S,Y_S = Cartesian coordinate

θ = angle (radian)

Thus, the AE events of active corrosion were used to locate and to calculate for the source identification using the source location calculation. The result was illustrated in the next topics and can be discuss in according to source location conception.

5. Result and Discussion

The condition monitoring of storage tank using acoustic emission signal can be used to detect the active corrosion. The results are represented as shown in figure 9-12.

The normal tank condition can be used to consider the AE event of active corrosion that it had nothing appearance on the tank bottom as shown in figure 10. The transient signal can be located at the tank bottom when it had the active corrosion to transfer ion between water and iron plate in corrosion process. The AE Events were located according to the real position of the iron plates that are soaked on the tank bottom as shown in figure 10 of 5 $inch^2$ and figure 11 of 2 $inch^2$. In figure 10 and 11, the horizontal axis was the X location (meter), the vertical axis was the Y location (meter). The dot graph, figure 10 (A), was represented as the AE Event located by the source location concept. The bar graph, figure 11 (B), was represented the cumulative AE Event to occur repeatedly during testing time of 2 hours.

From the old tank corrosion, as shown in figure 12, there are many AE events around the tank bottom and the AE event had grouped data but it was various around the tank bottom according to the condition of tank condition. In result of old tank, the source locations of corrosion signal were diffused around the tank and had not AE Event similar to tank that had corrosion plate soaked on the tank bottom. The AE Event was located within 5 $inch^2$ and could be seen with in boundary of real position on the tank bottom of 5 $inch^2$.

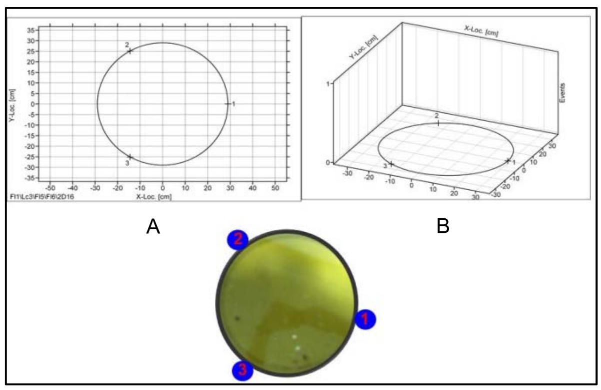

Fig 9 Tank No.1: Location of Corrosion Event

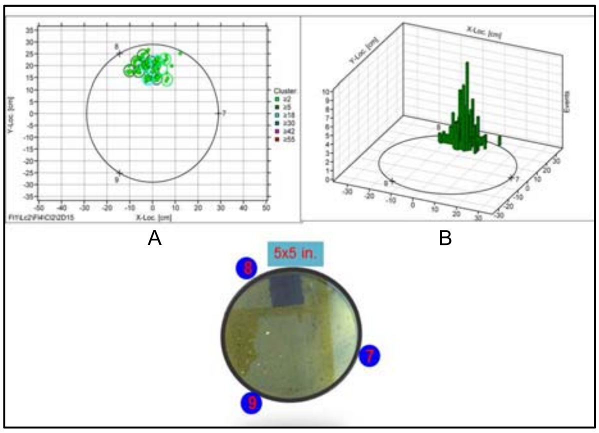

Fig 10 Tank No.2: Location of Corrosion Plate of 5 inch^2

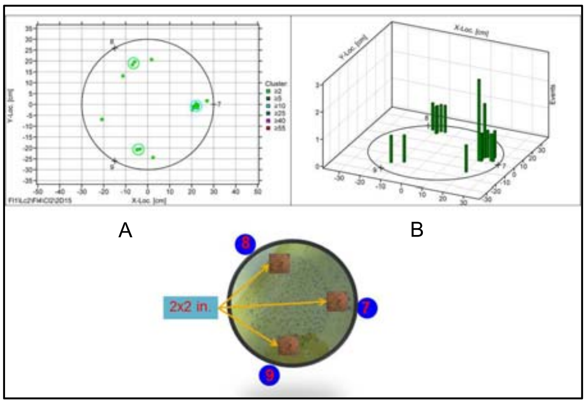

Fig 12. Tank No.3: Location of Corrosion Plate of 2 inch^2

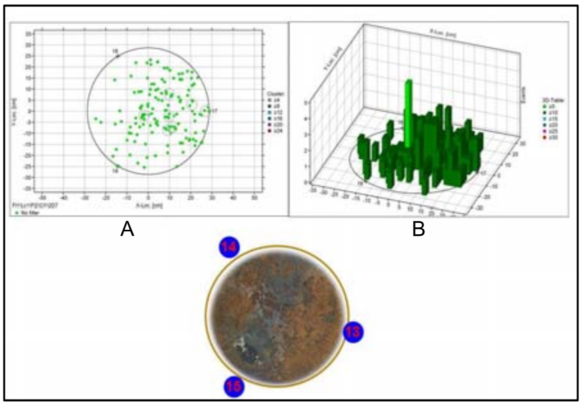

Fig 13 Tank No.4: Location of Corrosion Event

The elastic wave of Acoustic Emission can be used to identify the active corrosion of storage tank successfully in order to monitor the state of tank bottom for monitoring corrosion activities. Moreover, the cross correlation concept can be used to apply for source location to determine the location of corrosion as shown in figure 10 to 13 accurately.

The characteristic transient wave of AE signal parameter was detected in all of the experiments to identify the active corrosion during testing as shown in table 1. The values were represented by averaging that it had located the AE event on the tank bottom according to figure 11-13.

Tank No.	Acoustic Emission Parameters				
	Amplitude (dB)	Duration Time (μs)	Rise Time (μs)	AE Count	AE Energy
1	0	0	0	0	0
2 with (5 in^2)	28.7	400	28.6	12.5	9.38
2 with (2 in^2)	29	398	27	11	9.1
3	30.5	3098	100	98.83	174.5

6. Conclusion

The condition monitoring of corrosion detection using acoustic emission technology can be used to detect the active corrosion of an aboveground storage tank. The source location at tank bottom simulated by rust iron plate can be illustrated correctly location on the tank bottom and high accuracy when consider the location of the result. This technique can be applied for preventive maintenance program to monitor a tank bottom of storage tank to plan shutting down for internal inspection. This NDT method has a very benefit because the owners can avoid the dangerous damage of degradation corrosion lead to leak of a storage tank and can safe cost and economic of transferring product to another place storage. However, the result of acoustics emission signal can be used compare with another method of NDT technique, such as magnetic flux leakage (MFL) or tank floor scan, to map the result compared with the corrosion location to verify when the storage tank must open for internal inspection.

7. Acknowledgement

The authors wish to thank the Thai NDT PCL for their support and their instrument in research laboratory and to thank department of mechanical engineering, Mahanakorn University of technology, for location testing and facility.

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