The Effectiveness of Flaw Detection Caused by Cracking Using Acoustic Emission Technique

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Abstract. Several damage mechanisms act as sources of acoustic emission. In general, every mechanism that affects the integrity of the structure or equipment is a source of acoustic emission. This is due to the nature of the technique's principles, which is based on the fact that the material itself emits the signals by releasing energy during the degradation process. Particularly, damages originated from cracking mechanisms are primary sources of acoustic emission, having a high probability of detection (80% to 100%). This fact is actually discussed in various publications. The work presented herein discusses the principles of the technique, the origin of the phenomenon which allows monitoring the nucleation and the initial stages of diverse flaw mechanisms. A correlation with areas of stress concentration given by finite elements modeling is also discussed.
Keywords: Acoustic Emission, Finite Elements, Non-Destructive Testing, Global Inspection, Crack Detection, Damage Location.

I. Preface

Monitoring by Acoustic Emission (AE) is a non-destructive testing method (NDT). The basic principle of the technique is the detection of transient waves generated by the degradation process of the material, which in its turn is caused by the presence of anomalies in this material. These signals, or stress waves, are generated when the material is subject to thermal or mechanical stresses.

The two major features of AE technique are the ability to monitor a structure in a non-intrusive global manner, and to locate specific regions in the structure where the anomalies are likely to be found. The advantage of a non-intrusive global monitoring lies in the fact that the equipment or structures are monitored as a whole without significant interference in their operation, thus avoiding unnecessary production interruptions. The advantage of locating specific regions that show evidence of discontinuities, or other anomalies, is that other NDT techniques complementary inspections can be performed in these regions, and not in larger areas of the equipment, reducing costs and stop time to carry out these extra inspections.

II. Principle

The complete theoretical fundamentals of AE is an arrangement of several areas such ultrasonic, digital signals processing, spectral analysis, materials engineering, fracture mechanics and others. However, the description here is only an explanation of the basic concept of discontinuities growth when the material is subject to mechanical stress. Results of inspection carried out in an equipment or structure using AE become more useful when the properties of the technique, with its function of global detection and without operational interference, are properly understood. The concept of the technique is shown in figure 1.

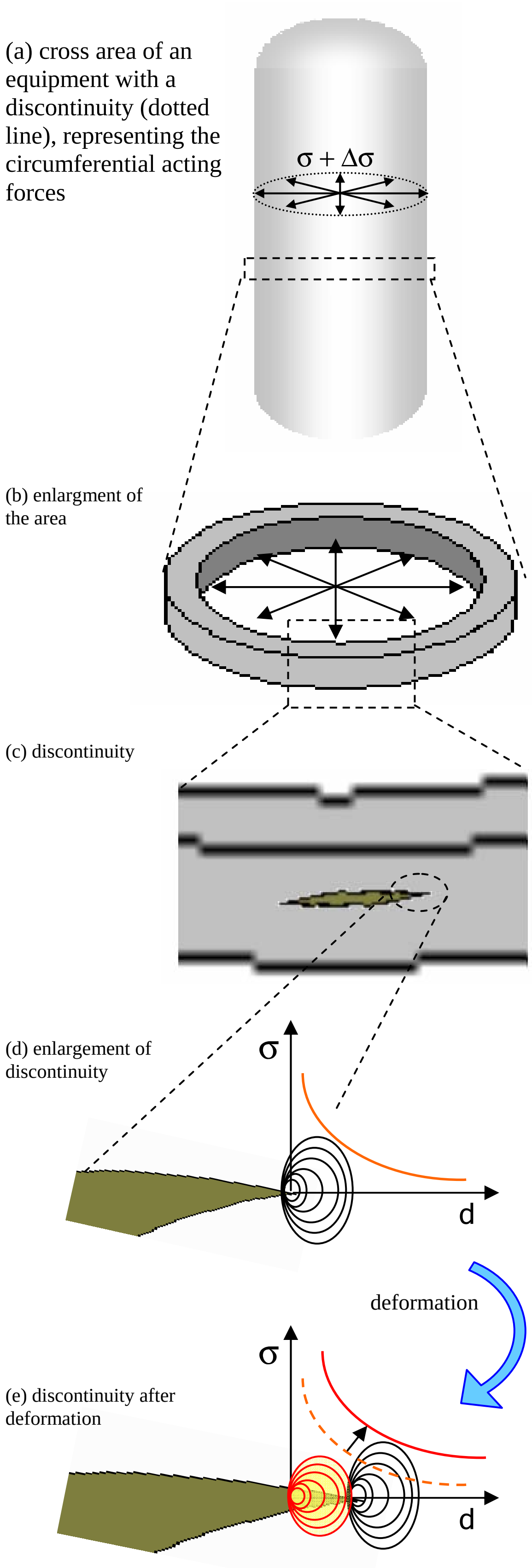

Figure 1. (a), (b) e (c) amplified image of the region where the discontinuity is located; (d) region of stress concentration at the tip of the discontinuity; (e)displacement of stress versus position after propagation of size.

The propagation of a discontinuity depends on the material from which the equipment is made. Material tenacity is one of the key parameters in propagation of discontinuities. Cracks with lower tenacity materials are more likely to propagate very quickly releasing all energy at once originating fragile fracture. On the other hand, cracks with higher tenacity materials are likely to propagate in ductile mode. K_I is the unity that defines stress intensification, and is represented by the equation: $K_I = Y\sigma\sqrt{\pi a}$, where ***Y*** is function of the geometry of a discontinuity, **σ** is the acting force, and ***a*** defect size.

The unstable rupture point, i.e., fracture instant will occur when the K_I value reaches the K_C critical value which varies in accordance with the thickness of a discontinuity.

AE technique in monitoring structure integrity of metallic equipment has been successfully applied due to the fact that the majority of materials enter into a deformation state before fracturing, which occurs at the tip of the discontinuity where stresses are higher. Figure 2 shows the behavior of a crack when subject to stresses exceeding the material creep stresses.

On figure 2 (d) and (e), we can see that at the tip of the crack there is a deformation region, represented by the concentric ellipsoid that shows the stress field. This area is a zone that will deform permanently before the rupture instant, i. e., the material in this zone enters into a plastic deformation state, and is represented by the yellow zone on figure 2 (e).

Detection and Location: Acoustic emission detection principle is fully applied here. When the material releases stored energy through plastic deformation, transient waves are generated and propagate until attenuated completely. During this propagation, the waves travel by the sensors, where the arrival time and its characteristics will be recorded by a monitoring system. These waves generated by deformation and propagation of discontinuity can be considered for illustration purposes as disturbances in the medium, which in this case is a metallic material, or for instance, like waves generated by a stone thrown on the water surface of a lake.

Transient waves of mechanical origin, when detected by the piezoelectric element of sensors, are transformed into an electrical pulse, which is generated by the potential difference in metallic elements at the edges of a piezoelectric component. These electric pulses are transmitted to a pre-amplifier that amplifies the signal. After passing through the pre-amplifier the signal is sent to a digital processing board that will process the signal, extracting relevant information to identify (type of anomaly) and location of AE source.

Two parameters are necessary to locate an active AE source: speed propagation at the wave front in a specific material and the arrival time at each sensor. The first parameter can be obtained in a table or even through measurements in the structure. The second parameter, which is made up of several values, is obtained automatically by the data acquisition program. Figure 2 shows the concept of detection and location of active sources. The location algorithm calculates the differences of signal arrival time in each sensor, triggering when the wave arrives at the first sensor. This implies that a sequence of values is calculated, and with the propagation speed is possible to calculate the position and origin of AE source.

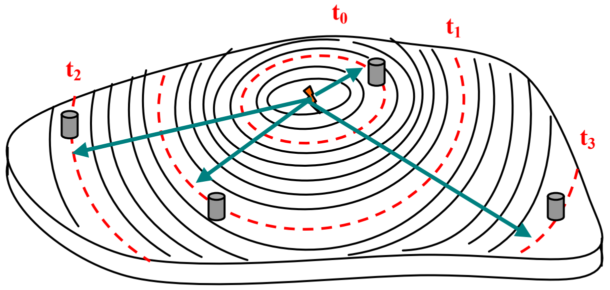

Figure 2. Location principle drawing. Two parameters are need: sound speed of material and arrival time for each sensor.

III. Statistics

As any NDT technique, or any other field, accuracy, effectiveness and repeatability are essential issues in the acceptability of a non-intrusive inspection technique. The graph on figure 5, took from “Assessment Matrix of In-Service Inspection” paper, presented at 6ª. COTEQ, Salvador-BA, Brazil, August 2002, show the results obtained in a study conducted with 251 equipment tested with AE technique and assessed with complementary testing [3]. After the AE testing, the equipment was subject to complementary testing to validate the acquired results. Validation results can be divided as follows: 1) active areas correspond with unacceptable damages by fracture mechanics; 2) damages found in active areas do not present criticity rejected by fracture mechanics in accordance with BS 9710; 3) discontinuities were not found in active areas; 4) discontinuities found in active areas considered harmless by fracture mechanics; 5) discontinuities found and rejected by fracture mechanics in inactive regions. The vast majority of equipment, over 80% fits in this first category. This result shows testing effectiveness in the detection of discontinuities that can harm the integrity of the equipment.

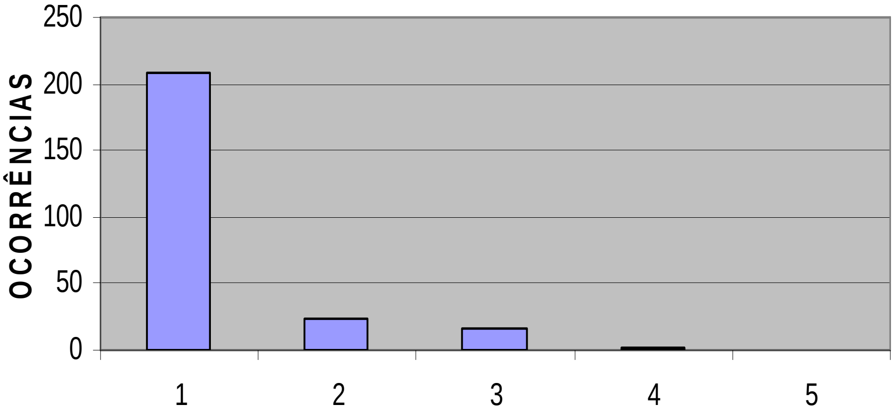

Figure 3. Number of occurrences for each case:
1) Active area correspond with unacceptable damages by fracture mechanics;
2) damages found in active areas do not show criticity rejected by fracture mechanics as BS 7910;
3) discontinuities were not found in active areas;
4) discontinuities found in active areas considered harmless by fracture mechanics;
5) discontinuities found unacceptable by fracture mechanics in inactive regions.

ASME Code, Edition 2001, Section V, Article 1, Page 15.2, Table A-110[5] is also a source of information about the probability of detection of several NDT techniques. This table (figure 4) shows the probability of detection of several testing techniques ranking from 1 to 3, where 1 is the larger POD (probability of detection).

AE testing is ranked 1, i.e., the probability of crack detection is of 80% to 100 % in any material.

Finally, another source of information is API-581, which deals with Risk Based Inspection (RBI). This standard describes several techniques, and again AE is the most recommended for detection of internal and superficial cracks.

Figure 4

NDT Method	VT	PT	MT	ET	RT	UT	UTS	AE	
Cracks all Products	3	1	1	2	2	2	3	1	

IV. Applications

There are several applications for acoustic emission: corrosion detection in tank floor, leaking detection, and detection and location of partial discharges in power transformers. However, the focus here is integrity assessment, where the larger failure agent is the cracking phenomenon, which can be generated by several damage mechanisms, such as fatigue, stress corrosion or hydrogen cracking.

Large structures, also called super-structures, such as load moving and transportation equipment, overhead cranes, highway and railroad bridges, cranes, reactor and many other large structures made up of large areas where is necessary to assure structural integrity, are a challenge for in-service inspection. The common practice is a sampling testing in selected areas, either due to failure history or studies in regions subject to in-service thermal or mechanical stresses. Finite element analysis has been increasingly applied to assess acting stresses; the method is extremely efficient to evaluate efforts during operation. This analysis can be further improved when complemented and balanced with field strain measurements using strain gages. Analyses of history and acting stress are important factors to decide the more adequate inspection samplings.

This decision is very important, for the reliability of an integrity assessment is directly associated with the sampling magnitude. It is also easy to notice that 100% reliability is only guaranteed with 100% inspection. Cost plays an important role. Here lies the big challenge for inspection: to reach higher reliability with lower cost. The conceptual solution is well known: the use of technologies that can be applied in a shorter time interval, carried out in-service, and as complete as possible. Acoustic emission is the technique that better meets these requirements and is the best recommendation for a non-destructive testing. We would like to highlight two relevant aspects in the next paragraphs. The first is the coherent result between finite element analysis and acoustic emission testing. The second one is the detection of cracks in a previously tested structure in areas with higher stress concentration. These two aspects show, in the first case, the ability of acoustic emission testing to detect failures in regions with higher stress concentration which can be associated with heavy loads in specific parts of the structure, or due to a discontinuity in a region of low stresses. The second aspect is the reduced inspection reliability when only aimed towards regions of higher acting loads, and disregards high stress concentrations due to stress intensifiers, such as manufacturing failures in unforeseen regions in finite element analysis, or even occasional corrective maintenance or changes in the project that harm the original load distribution.

Magnetic particle and ultrasonic localized inspection showed several fatigue cracks that thanks to the superficial condition could be ground. Figure 6 shows an overview of the region and details of detected failures. This short example shows the effectiveness of a global inspection, directing the inspection to regions with real need, making inspection and maintenance activities more reasonable. Although finite element analysis showed two areas with stress concentration (not necessarily defective areas) only one of them had defects. In this particular case, to present the results in this paper, inspections were carried out in both areas. In the example we explained how an inspection, even by sampling, can lead to unnecessary labor, adding inspection and maintenance cost, and of course impairing profits. There is another danger in directed sampling testing at higher stress regions. We can fail to inspect defective areas and lead to a failure in the equipment.

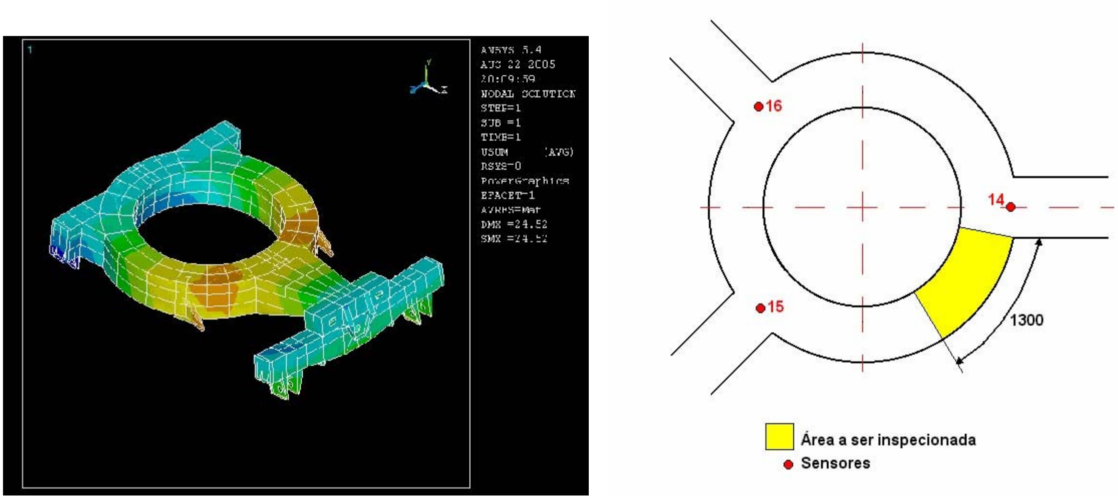

Figure 5. Top: result of a finite element analysis. Bottom: result of acoustic emission.

Figure 5 shows a finite element analysis of a critical component in an ore conveyor. The figure on left shows higher stress regions (dark red areas).

The figure on right is the result of an acoustic emission monitoring, appointing region with structural damages. The result shows clearly where acoustic emission testing appointed one area with higher stress as a region with defects.


Figure 6. Detail of a localized inspection.

Inspections in part of a structure instead of global inspection indicate less reliability. The risk is reduced when the criteria to choose a sample is based in predominant damage mechanisms and its respective defective areas. The history of recurrent failures is also an important information source, however it deals only with what is already known and only with failures that caused operational stops, and as rule are of unknown origins. We also have situations of corrective maintenance (sometimes emergency ones) and project modifications (sometimes to meet demands of increasing production), which change stresses distribution, leading to unforeseen conditions in calculation estimate (including finite element) and conditions of operations not reported in the equipment files. These situations, unfortunately common, reduce highly the inspection reliability, integrity assessment and consequently the operational reliability. Here lies the major reason to apply global inspection as shown in the previous chapter.

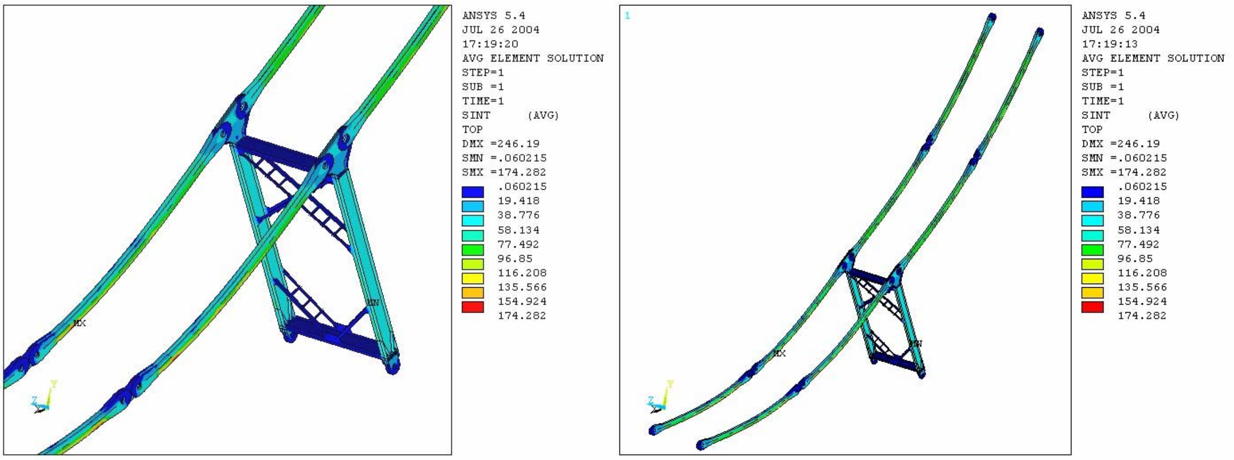

Figure 7. Finite element stress analysis in tie rods

The objective is to avoid stops due to failure problems as follows. In a tie rod, finite element analysis showed low loading weights, as Figure 7. Due to a manufacturing failure that propagated when in-service operation and after the load test, the tie rod failed in a region considered as of low acting stress. The individual, of course, had no reason to suspect this defect. This information should have been considered in the calculation, adding a factor of stress increasing, which would change completely the scenario of stress distribution. Figure 8 shows the failure.

Figure 8. Detail of failure

V. Conclusion

After completing the analysis process of detecting a discontinuity by acoustic emission, as well as the statistical analysis confirming the effectiveness of crack detection, and it is possible to conclude that an improvement in the operation reliability is the key result reached when we change inspection activity and integrity assessment for global sampling. It is also worth to mention that resources are streamlined, i.e., costs reduced with corrective maintenance, and availability of the equipment increased with reduced idle time.

VI. References

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