

## **ACOUSTIC EMISSION MONITORING OF IN SERVICE HARBOR CRANES IN ORDER TO PROGRAM MAINTENANCE OPERATIONS AND INSURE SAFETY MANAGEMENT:**

### **Abstract:**

The plant of ArcelorMittal Fos-sur-Mer (France) is producing 4 million tons per year of hot rolled steel coils.

A significant part of the production is shipped by boats.

Two "Titan" harbor cranes are used in order to transfer the 40 tons coils on boats.

These cranes have been manufactured in the 70's and some significant fatigue cracks have been discovered in 2015. Some significant repairs were realized on the metallic structure and inspection plan has been modified.

In order to detect unknown fatigue cracks propagation or initiation, an Acoustic Emission monitoring has been performed on the two harbor cranes. Especially for areas where traditional nondestructive testing methods are difficult to use.

After the proof tests, a specific procedure has been defined to set the instrumentation. Then an appropriate signal processing has been developed using pattern recognition analysis with *Noesis* software to characterize and identify several AE sources as fretting noises due to crane rotation, in service shocks, mechanical impacts...

The AE results of the monitoring of the first months indicate the activity of sources that are correlated with propagating fatigue cracks detected by dye penetrant and ultrasonic in area where even visual inspection is sometime difficult to perform. AE has demonstrated also the ability to verify in such conditions if a known indication is propagating or not.

Acoustic Emission monitoring has been pushed forward as a very flexible and powerful nondestructive tool for in service monitoring of complex machinery as Titan crane. Included in the inspection plan it gives information about the propagating defect in real time allowing to an efficient maintenance policy.

Topics: AE testing (fatigue cracking, asset management monitoring, maintenance planning etc.)

Contribution is preferably  
suitable as: oral presentation

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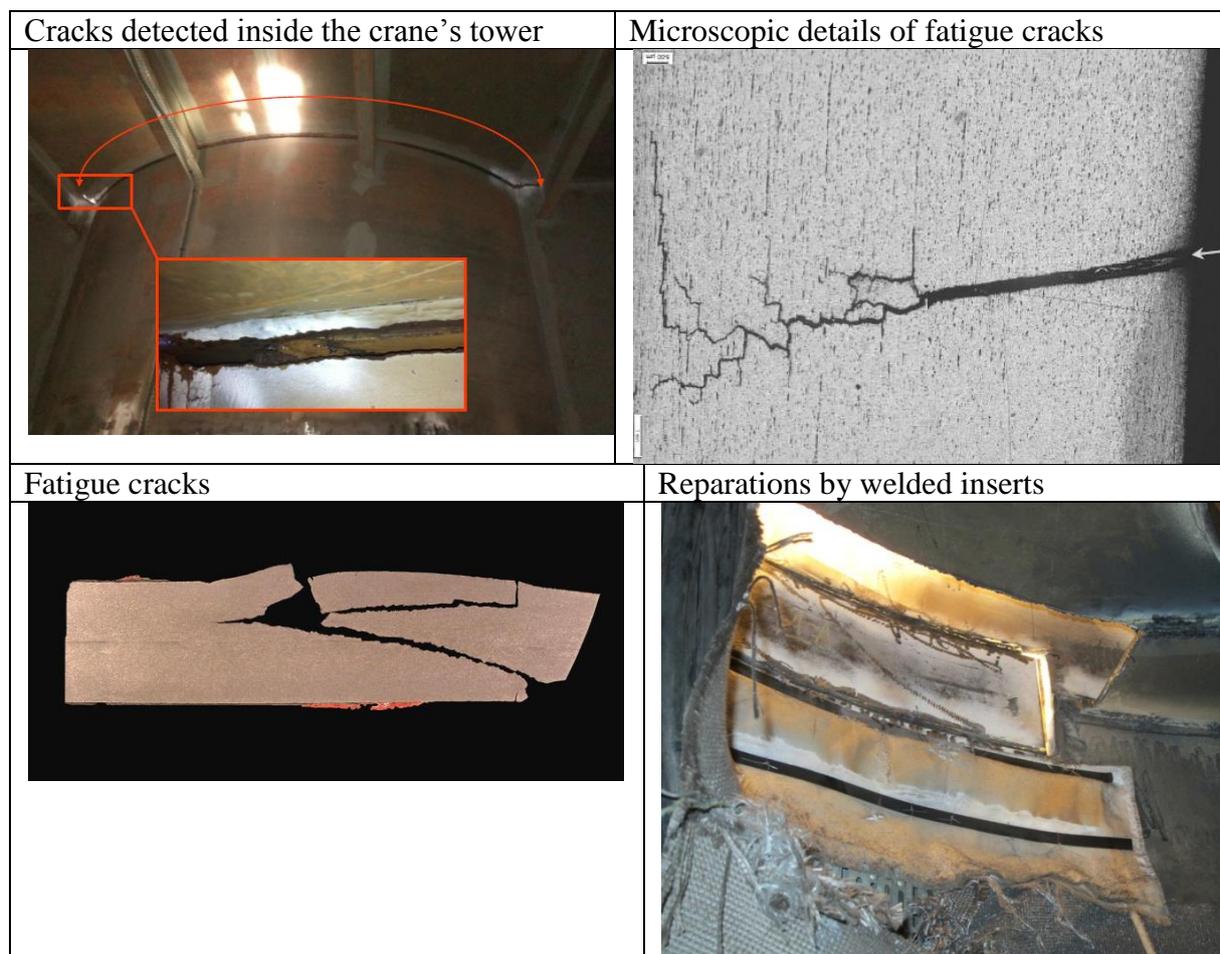
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## 1. Industrial context

These heavy duty cranes are aged and some significant fatigue cracks have been discovered in 2015. Important repairs were realized on the metallic structure and inspection plan has been modified and improved. Nevertheless the base metal is highly stressed and rupture mechanic calculation indicates that new cracks can be initiated even in the repaired area. In order to detect unknown fatigue cracks initiation and propagation, an Acoustic Emission monitoring has been implemented on these two harbor cranes. The internal structure of the crane is quiet complex and traditional nondestructive testing methods are difficult to apply with sufficient efficiency. Furthermore the entrance in the internal part of the crane is not allowed during operation because of safety reasons. These two cranes have a high utilization rate and that is also why the initiation time of crack could be rapid.



ArcelorMittal is the world's leading steel and mining company. Guided by a philosophy to produce safe, sustainable steel, it is the leading supplier of quality steel products in all major markets including automotive, construction, household appliances and packaging. ArcelorMittal is present in 60 countries and has an industrial footprint in 18 countries. The plant of Fos-sur-Mer (south of France) is one of the biggest plants producing 4 million tons of hot-rolled-steel coils (coke and sinter plant, two blast-furnaces, two oxygen converters and continuous casters, one hot-strip mill and finishing and pickling lines)

Mistras Group is a leading global provider for asset protection solutions & technology-enabled solutions used to evaluate the structural integrity, industrial and public infrastructure for aerospace, Petrochemical and Energy industry. Mistras develops innovative products and technologies for Non-Destructive Testing used for qualification or requalification tests of complete structures and furthermore 24/7 on-line monitoring of existing structures.

## **2. Principe of the measurement**

Acoustic Emission (AE) is the result of sudden energy release within a material, which appears as elastic wave. This technique is widely used as a non-destructive testing technique for fitness for service evaluation in industrial field. AE is also a powerful tool to characterise and understand damage initiation and crack propagation. Most of all microscopic damage mechanisms were studied and correlated with AE signals.

Many developments in AE technology, followed by significant developments in AE instrumentation, have occurred in the past ten years. In some cases, analytical calculations of wave propagation can be done for simple structures using combination of theoretical solutions and signal analysis. However, this technique is mainly experimental, the best tool for signal analysis is pattern recognition using databases combined with source characterisation and location.

That is why tools based on signal pattern recognition have been used to allow complex problem analysis (multisource and different propagation patterns). A multiparametric analysis using pattern recognition and neural network via Noesis software was performed to isolate signals such as fretting noise, mechanical noise from crane and define a real-time analysis based on AE features [1, 2]. Nevertheless, in order to feed any pattern recognition analysis, different experimental measurements have been made on samples and small structure to feed the data base used in real time.

Because of the development of the instrumentation and data analysis software, the long experience of applications for in-service testing of pressure equipments or infrastructures in various industries, now Acoustic Emission (AE) technique is mature to be used as an on-line system to monitor the mechanical integrity of while in operations [4, 5, 6].

## **3 Instrumentation.**

The environment of the crane is very noisy from a mechanically and electromagnetically point of view. The plant of ArcelorMittal Fos sur Mer is producing steel, it means that there is in the neighborhood a lot of high power electric engines moving bridges cranes. Furthermore some workshops are using directly huge current intensity. That is why we choose first integrated preamplifier sensors. These sensors were replace very soon by smaller sensors to better fit to internal concave curvature on the internal structure and particularly to resist to future welding repair of local damages. The differential sensors R15D selected are connected an in line differential preamplifier directly with high quality single core BNC cables to the AE acquisition system. Because two cranes have to be monitored two independent 16 channels Express 8 systems are used. They are powered by the crane via an uninterruptible power supplies system to prevent loss of powering and insures a better electrical parasitic noise rejection. AE systems are installed inside the non-rotate part of the crane.

Sensors are maintained with magnetic holders and coupling is made with silicon grease. In case if AE source is located too close to AE sensors, those sensors can be dismantled easily in order to correlate and to measure the extension of the indication with traditional NDT. Furthermore it will avoid the degradation of sensors if a repair should be achieved (fig. 1). Some welding work can be done without removing the sensors and this is the reason why we stop to use integrated preamplifier (risk of local overheat during welding).

Of course after each operation, sensor coupling is checked locally with Hsu Nielsen source and Auto Sensor tests for the complete set of sensors. Neighbor's sensors receive the transmitted elastic waves and allow verifying the good transmission on well coupled sensors.



Figure 1: picture of a sensor near crack area.

Prior to starting monitoring, preliminary experiments have been conducted to define an appropriate procedure, to choose and adapt AE instrumentation and appropriate signal processing to eliminate as much as possible mechanical noise and at least recognize it in order to eliminate it by post processing.

As the internal structure is very complex, all accessible discontinuities have been simulated by Hsu Nielsen (NF EN 1330-9) source to improve the location strategy.

In addition to traditional frequency filters, multiparametric front end filters have been set up to reduce, in real time, the noise activity and to limit the large amount of collected AE data. The size of the generated files is driven by computer in order to secure data files and to facilitate the transfer of collected AE data to Mistras office processing center. The periodicity of data transfer and analysis, have been increased from two days at the beginning of the monitoring, to a week according to the first results of cracks propagation kinetic measurements.

**4 The monitored structures: two Titan cranes.**

Two Titan harbor cranes (N° 730 and 731) are used to transfer the 40 tons coils into the boats in the harbor side of Fos sur Mer. The cranes are moving on rails along the piers to approach the boat (fig. 2). Then to load it they have to rotate to deliver the 40 tons coils.

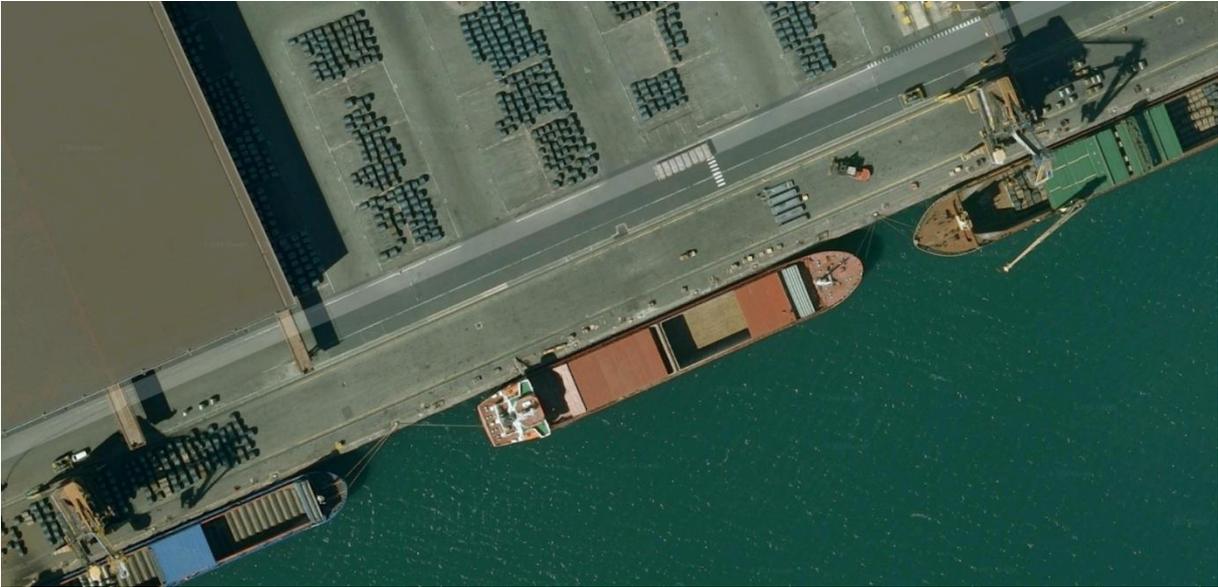


Figure 2: situation of the two cranes on the harbor of Fos sur Mer.

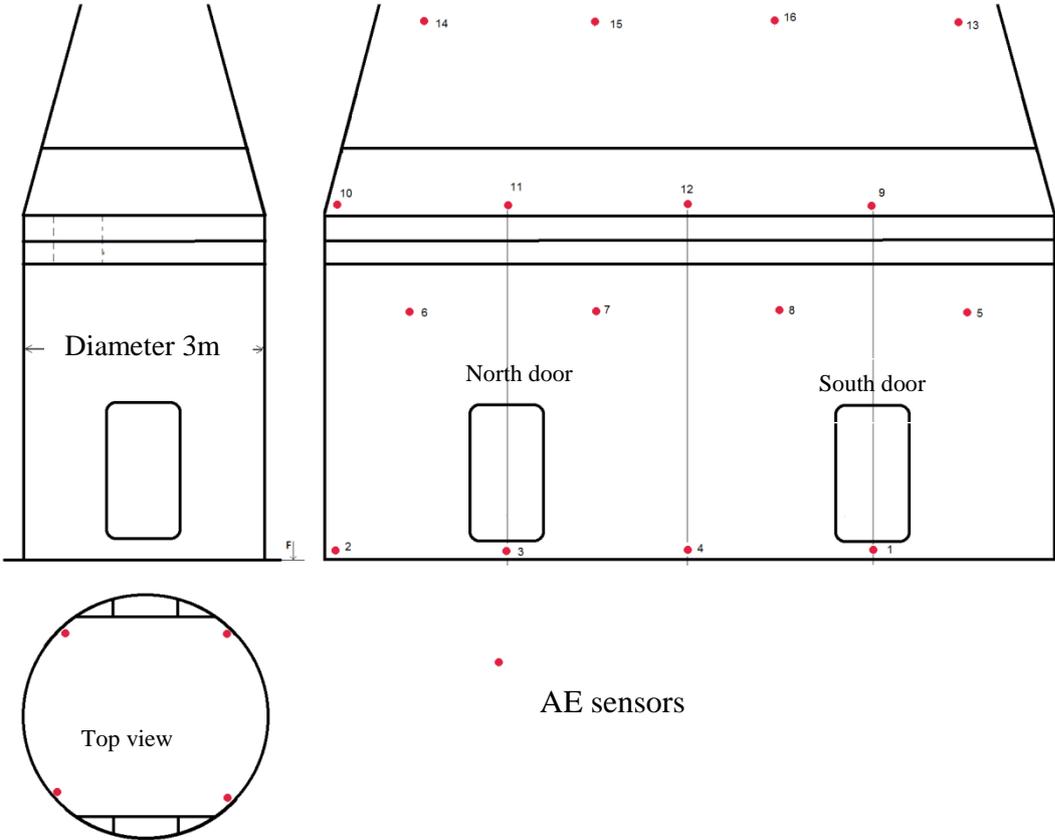


Figure 3: schematic drawing of the monitored fixed part of the crane with the position of the sensors.

The main cracking area discovered in 2015 on the crane internal structure. It can be represent by a cylinder ended with a conical shape which is represented on figures 3 and 4. Figure 3 is showing the sensor layout. At the level of sensors 9 to 12, there is the tread pattern of the crane where the rotation is guided.



Figure 4: View of N°731 titan crane and area of interest.

## 5 AE Results.

Just after the initial major repair in September 2015, both cranes have been tested mechanically with different “proof” test sequences. Some dynamic tests with no charge have been performed and also some progressive loading proof test at 55 and 66 tons.

The progressive phases of loading at the maximum load did not generate a significant AE activity. The main recorded activity has been detected during dynamic tests with no load with the crane boom lifted near the verticality. The location processing indicates localized activity mainly in the tread pattern in front of bearing rollers. Figure 5 gives an example of location map during dynamic test of N° 731 crane. No other significant indication has been detected during these loading tests only stress release in the tread pattern area.

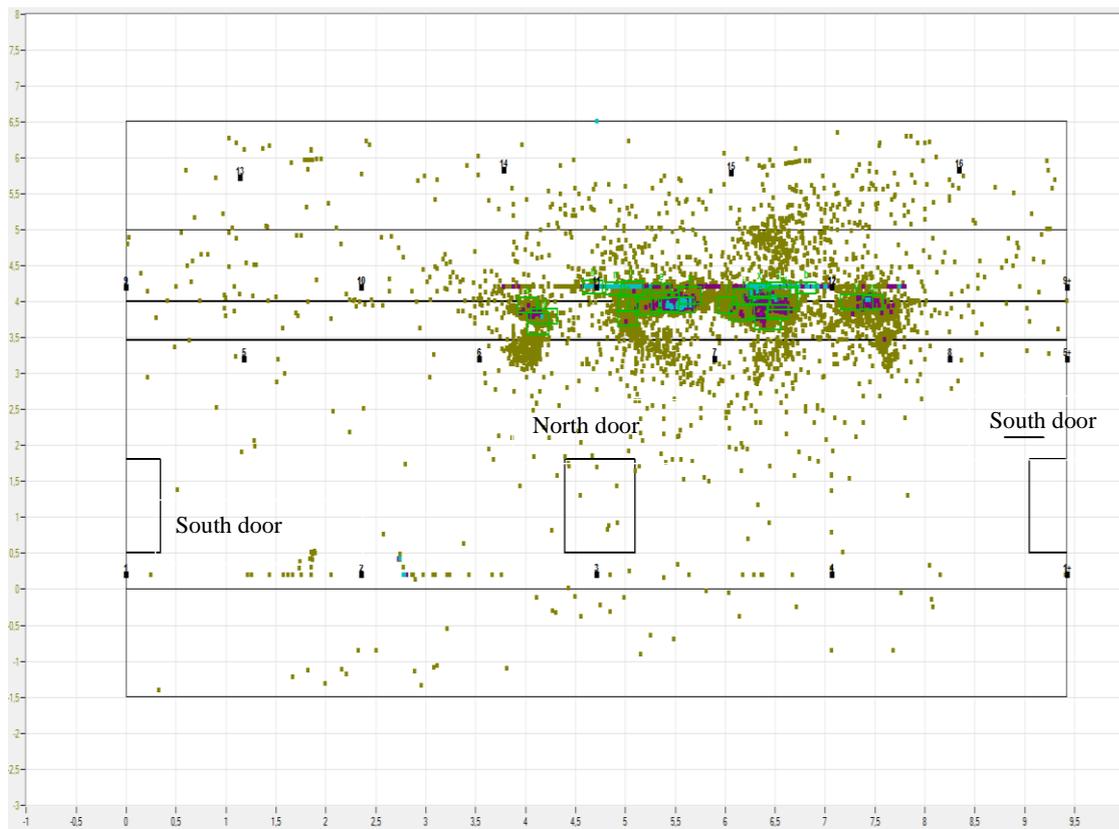


Figure 5: Location AE Map of Titan crane during dynamic phases of proof test.

Based on the analysis of proof test, an adapted AE filter has been built. After this real time noise rejection of data the monitoring is producing readable and genuine information.

The most difficult part of the processing is the fretting noise elimination in existing cracks on the external tread pattern.

The AE sources give rise to real AE that cannot be eliminated by AE data processing. The AE sources have to be carefully identified and characterized by localisation. These external damages are not so important in term of integrity of the crane but according to the aging of the tread pattern, they begin to be more and more emissive.

The two cranes are monitored since September 2015. Over a period of more than year AE analysis has given several significant warnings. These warnings were immediately followed by visual inspection, magnetic particles inspection (MP) and ultrasonic (UT).

Figure 6 gives an example of one week location map that indicates several sources crossing the warning level in term of cluster concentration and emissivity history. After internal inspection (MP and UT) and cracks sizing, it has been decided to repair the area of source 1 and 2. Figure 6 shows also an important AE emissivity near to the zone of the tread pattern (sensor 10, 11 and 12).

Figure 7 give evidence of superimposition of multiple cracks propagations in the area near to the south door (sensor 3).

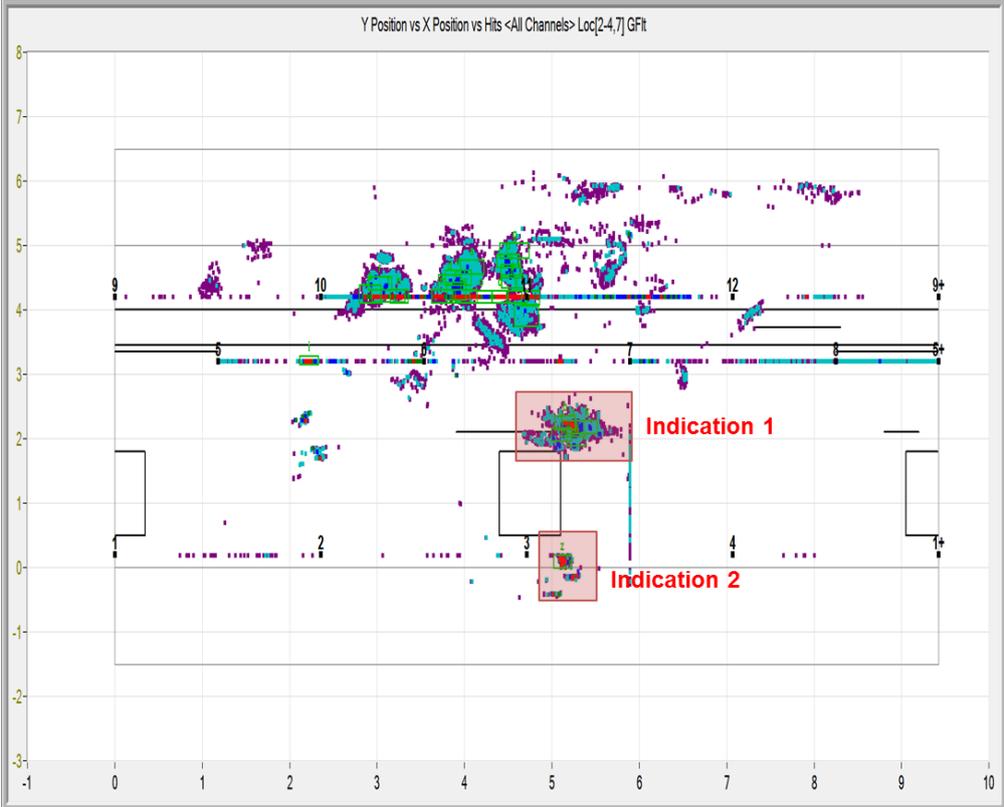


Figure 6: One week location map on N°730 Titan crane.

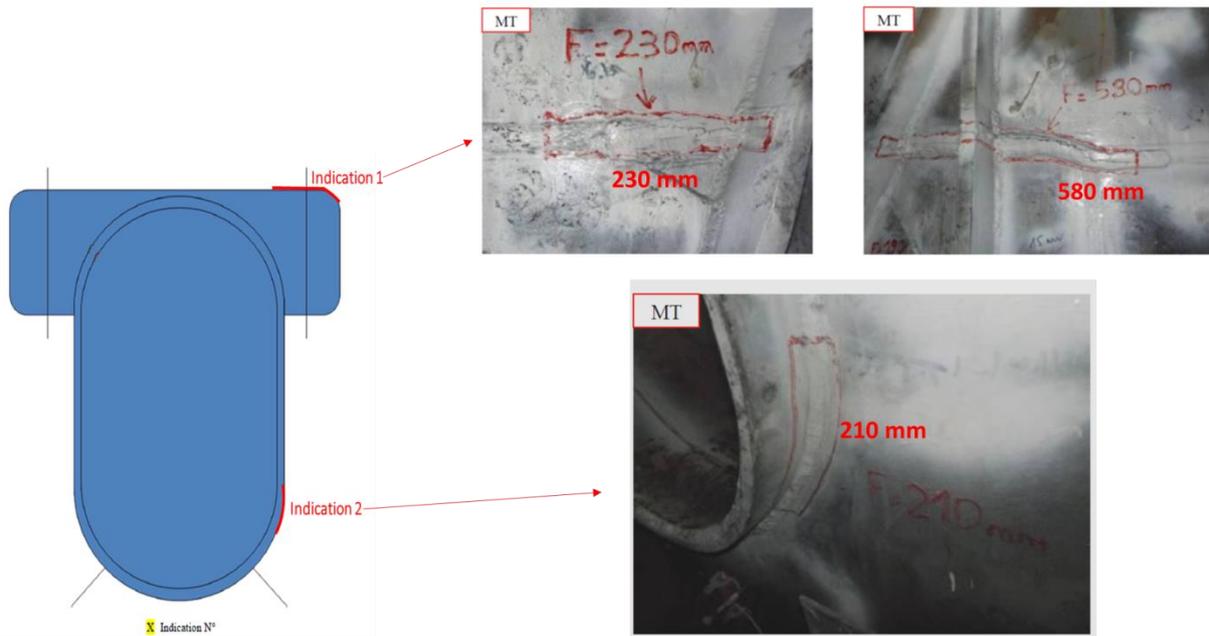


Figure 7: sizing of the indications in the AE source areas (MP and UT).

The monitoring results just after repair gives a great reduction of AE activity in these 2 areas.

Table 1 and 2 summarized the correlation between AE results (indications) and the inspection using MT and UT techniques. Those tables confirm that the majority of critical AE indications have been confirmed and sized using traditional nondestructive techniques. Once a critical AE indication is confirmed reparation were scheduled and carried out before restart.

During this period of monitoring (year 2015-2016), traditional NDT campaigns were triggered on the Titan crane N° 730 and N° 731.

One significant indication sized with MP did not exhibit any AE signature. According to inspection history, this particular indication recorded in September 2015 (with the same size) has been considered at this time as no critical. This indication was not repaired because it appears to be only a bad weld overlay and not a real crack. Even if it is obvious, this example is given evidence that a significant indication size (several mm) which does not propagate, does not generate any AE emissivity.

| Date              | AE Indication          | Control MT & UT    | Results & Decisions   |
|-------------------|------------------------|--------------------|---|
| 09/2015 – 10/2015 | 7 critical indications | 7 Cracks confirmed | Shut down the crane and significant repairs (6 weeks shutdown ) |
| 11/2015 – 01/2016 | 4 critical indications | no access          | Shut down the crane and significant repairs (1 day)             |
| 01/2016 – 08/2016 | 3 critical indications | No full access     | Limited area repair   |

Table 1: Correlation between AE results and control using MT & UT and the following repair decisions for the crane N°730

| Date              | AE Indication  | Control MT & UT                      | Results & Decisions                                  |
|-------------------|--|--------------------------------------|--|
| 09/2015 – 01/2016 | 5 critical indications                               | 5 Cracks confirmed                   | Shut down the crane and significant repairs (2 days) |
| 01/2016 – 04/2016 | 6 critical indications [trade pattern & other areas] | Limited access<br>3 Cracks confirmed | Limited area repair                                  |
| 04/2016 – 08/2016 | 4 critical indications [trade pattern & other areas] | 4 Cracks confirmed                   | Shut down the crane and significant repairs (2 days) |

Table 2: Correlation between AE results and control using MT & UT and the reparation decisions for the crane N°731

## 6 Conclusions.

AE monitoring has been applied with real success on two heavy duty cranes over a period of more than one year. AE on-line asset monitoring provides plant personnel the ability to detect indication at an early stage, the growth of a crack and efficient warning. This is made possible by correlating the AE located activity with other process variables. AE analysis has several times declare warning. These warnings are followed with traditional NDT technique for cracks sizing which finally trigger repair operation. As the time goes, the period between warning and repairs increase significantly. It gives an indication that the way of repair can influence the re-initiation of cracking.

This industrial application described in this paper showing the benefits of this approach to enhance process safety, prevent catastrophic failures, reduce maintenance and repair costs, reduce number of inspections, prevent operation interruptions, improve risk management ...

These successful results conduct to scheduled Monitoring until the replacement of the tower cranes of course while the crack propagation can be handled.

## References

- [1] Anastassopoulos, A., A., Vahaviolos, S., J., Kouroussis, D., A., Vionis, P., Lenain, J., C., Proust, A., 'Analysis of Acoustic Emission Data from Wind Turbine Blade Testing Using Unsupervised Pattern Recognition', Proceedings of the 15th International Acoustic Emission Symposium, Tokyo, Japan, 11-14 September 2000
- [2] Proust, A. ; Lenain, J. C. ; Utilisation de la technique d'émission Acoustique pour le contrôle de structures en matériaux composites collés Contrôle non destructif de l'endommagement des matériaux collés 7ème JEFUEA'2002 – Octobre 2002
- [3] Work in progress: CEN/TC 138 WG 7 : In service AE monitoring of metallic pressure equipment and other structures - General requirements
- [4] Watson, J.R. ; Yuyama, S. ; Pullin, R. Ing, M. ; Acoustic Emission Monitoring Applications for Civil Structures, Bridge Management 5, Surrey University, UK 11th -13th April 2005
- [5] PROUST, A. ; LENAIN, J-C. Surveillance en service et à distance des ESP par émission acoustique. ESOPÉ 2010 Paris -30 Septembre 2010
- [6] Proust, A. ; Lenain, J. C. ; Faure, T. Méthode de monitoring de la corrosion localisée par la technique d'émission acoustique : information diagnostic et aide à la décision, Congrès matériaux, Montpellier, 24-28th of November 2014.