TUBE CRACK DETECTION BY AE MONITORING OF DEEP DRAWING OPERATIONS IN THE AUTOMOTIVE INDUSTRY

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Abstract: The uses of Acoustic Emission (AE) in process monitoring, particularly in the automotive sector, are little known but very varied (welding, straightening, drawing, machining, etc.)The most common use is no doubt in the straightening of gear box and steering rack rods.
Tears or cracks may occur when tubes are formed or deep drawn. AE can be used to detect the point in the process where the crack occurs (in the case of multiple step processes or multi-station presses). Once this crucial point has been identified, it is then possible to adapt the production process or the metallurgy in order to prevent this damage from occurring.
A press has been instrumented in order to be able to continuously control the production process. The first step when defining the feasibility of a process is performed using a multi-purpose AE system such as those used in research laboratories. Once the process has been clearly identified and the process noise has been characterized, a simplified control system is then defined and put in place on the production lines. Today, the mill decided to first study the localization of the weld seam before implemented the AE process monitoring.

Introduction: During fabrication in the automotive industry, deep drawing operation of welded tubes is susceptible to produce cracks formation in the most strained area. The most common used one hundred percent non destructive testing method in visual inspection after swaging. This operation takes time. The customer risk is guarantee but not the supplier risk if we generally scrape pieces without flaws.
AE monitoring has been tested on a production machine in order to identify cracked tubes. The initial intent of using AE during forming process is to detect propagating cracks but also to identify the most damaging stage of the process.

Acoustic Emission (AE) is the result of sudden energy release within a material, which appears as elastic wave. A piezoelectric sensor mounted at a genuine area in contact with the structure to monitor, transforms elastic waves to electrical signals (hits) gathered with an appropriated AE system (fig. 1). The AE signature of many damage phenomenons as localised plastic strain, twinning, ductile and brittle fracture for metallic alloy, has been detected and characterised.
This technique is widely used as a non-destructive testing technique for fitness for service evaluation in petrochemical field. AE is also a powerful tool to characterise and understand damage initiation and propagation. Most of all microscopic mechanisms has been studied and correlated with AE signals. The main interest of AE technique is, that is a real time and a global technique that can be implemented in an industrial machine without any modification of the process.
Some application in the automotive industry in the 70^{th} was welding process monitoring. Nevertheless some application has been developed for cold working operation as coining application for fuel injectors [1].
Steering unit is a safety component, where straightening is not allowed after thermal heat treatment if it is not verified that the straightening operation did not produce cracks [2]. This is a reason why straightening machine controlled by AE has been developed in order to guarantee that no crack occurs during process of Steering unit.

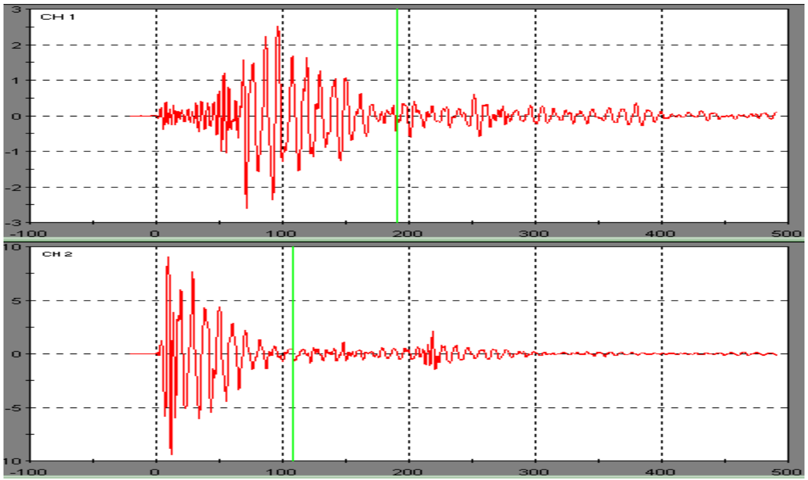

Figure 1: example of AE hits

In this case, the crack is initiated from brittle rupture of hardened surface and the crack size can be quite big and sometimes can lead to rupture. It gives raised to high amplitude hits, easy to insulate and detect.
During the production of tube, the metal is strained, bored, cut in the same time, and signal processing has to be made to differentiate ductile crack propagation from normal plastic deformation or ductile tearing.

Industrial product:
Vallourec produces especially tubes for rear axles with B53 5105 steel with a longitudinal weld. Before transformation, the tubes under interest are 32 mm of diameter, around 1000 mm of length and thickness of 2 mm. The welded tubes are cold drawn out with diameter size accuracy of 1/100 mm. Then they are 100 % controlled by automatic ultrasonic inspection with a notch threshold reference of 0.2 mm and also by Eddy currents in order to match with quality requirements of automotive industry customers. After final deep drawing, visual inspection is performed to discard possible cracked tube. With visual inspection one of the consequences of visual control consists in overestimate the number of defective pieces and increases the percentage of waste. Tubes with superficial scratch are often rejected. An objective criterion to define the severity of a defect is a standardised fatigue test. It is a long duration destructive test and it is only applied statistically but upon all production batches. The goal of this collaboration between CEV and Euro Physical Acoustics (EPA) is to use acoustic emission to save time during production and optimise the severity of rejection criteria.

Instrumentation set up and transformation steps:


Figure 2: general view of the pressing machine

The pressing machine is equipped by 4 moults. The tube is formed with 4 successive steps as it goes from moult 1 to 4 (called position 1 to 4), but all the moults are filled with one tube and all the steps are performed in the same time with successive tube. That means 4 tubes are simultaneously operated during the closing of press.


Figure 3: Detail of the inferior and superior part of moults from the left side

The complete process can be described as below with four positions with several steps for each:
- Introduction of tube
- Tube rotation according to weld position (CCD video camera)
- position 1 step a : deformation
step b: expansion of tube ends
- position 2 step a : tube maintain (no strain)
step b: flattening of tube ends.
- position 3 cutting of tube ends
- position 4 cutting of tube ends
- Exiting Tube
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This machine can produce from 80 to 90 pieces per hour and the real time inspection should not reduce the production rate.

The four positions are monitored with 2 AE sensors PAC R50 type (500 kHz resonant) fixed on the inferior part of the moult. The frequency range of measurement has been determined by preliminary tests. The goal was not only to maximise signal to mechanical noise ratio, but also to try to separate at least signals due to propagating cracks from signals produced by plastic deformation.
AE signals (hits) are amplified and driven to an 8 channel Physical Acoustics DISP system. 8 channels are used because the moult is constituted with distinct parts and it has been supposed that cracking could take place within the 4 positions. From an AE point of view, it is also necessary to determine if AE hits are coming from outside of the moult or not.
A parametric input is used to synchronise AE with pressing step. After first tests, time windows are set up in the acquisition to eliminate identified mechanical noise from tube driving and positioning.

Methodology:
This study has been conducted in 3 phases consecutively.
The first phase is used to characterize the process; therefore only one tube is introduced in the pressing machine. That means that only one moult is working at one time and the tube is driven from position 1 to position 4.
This operation has been done several times with a no defective tube and in order to identify the noise produced by all the steps, validate the instrumentation setup and qualify the scattering of AE from plastic deformation.
The purpose of the second phase is a study of AE interaction due to the simultaneous forming of 4 tubes in a four different moults which is the real production conditions.

The last phase has been driven by a Tagushi statistical study plan [3] with tubes having artificial defects. Because it was difficult to produce sufficient number real defects on purpose, it was made the assumption that artificial defect will propagate under forming stresses.
This study plan was defined in collaboration with the REX of operator of the pressing machine in order to define the most genuine parameters that can influence the crack formation or propagation. The objective of this plan is to show the influence of artificial defect size and configuration on cracking with a limited number of experiments.

Results and discussion:

The number of tubes with artificial defect present in the same time in the machine has been investigated during preliminary experiments. Therefore, it has been decided to study the worse situation i.e. only one potential defective tube in the machine at the same time.
After preliminary measurements and statistical study plan completion, 3 parameters have been kept under interest, depth of defect, location of defect inside or outside weld seam and longitudinal position of artificial notch.
The artificial defects are 10mm long electro-eroded notch with a depth of 0.1 or 0.2 mm. They are situated longitudinally at 20 mm from the end of tube or in the middle at the tube. Only one notch per tube was made. The first results show clearly that an artificial defect in the middle of the tube did not lead to any evidence of crack propagation neither with visual inspection technique nor AE measurement.
Therefore the longitudinal position parameter was not more investigated.
Visual inspection was performed before and after forming on all the tested tubes.

Parameter A: state 1: notch is on outside of weld seam
State 2: notch is on inside of weld seam
Parameter B: state 1: notch depth 1/10 mm
State 2: notch depth 2/10 mm
The chronology of these experiments is shown in table 1.
8 tubes with artificial notch are pressed within 45 tubes without notch in a manner than only one potential defective tube in the machine at the same time (fig. 4).

	Configuration A-B
5 tubes without notch	
1D	11
5 tubes without notch	
2D	11
5 tubes without notch	
3D	12
5 tubes without notch	
4D	12
5 tubes without notch	
5D	21
5 tubes without notch	
6D	21
5 tubes without notch	
7D	22
5 tubes without notch	
8D	22
5 tubes without notch	

Table 1: chronology of tests

Figure 4: automatic filling of the pressing machine

The history plot of AE allows correlating step of forming and AE signature.

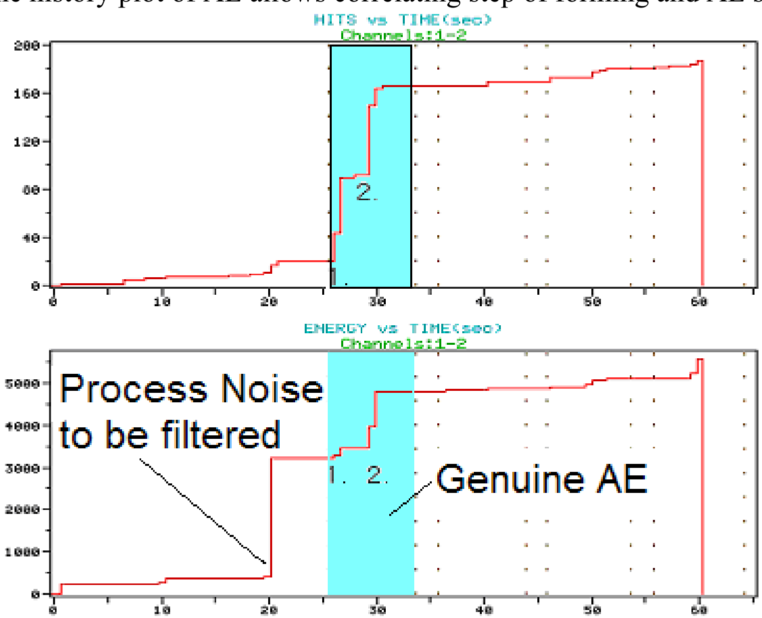

Figure 5: Hit and energy evolution versus time at position 1.

- Mark 1: position 1, step a (deformation)
- Mark 2: position 1, step b (expansion of tube ends)

The first steps of signal processing have been performed during preliminary experiments. It consists mainly in time windowing and area localisation for respectively elimination of mechanical noise and AE source position identification.

Neural networks have been used to try to separate AE from normal plastic deformation and AE from ductile crack formation. Only the last phenomenon is under interest. The result was: it can not be separated with by AE hit characteristics only. It is in agreement with the metallurgical assumption that both phenomenons have the same microscopic deformation phenomenon. Nevertheless we make the hypothesis that the activity is greater when cracking occurs and the amount of energy per hits is enhanced.

High AE activity has been detected for tube in position 2 during setting of synchronization. Then, visual inspection of this tube has confirmed presence of important crack and bad deformation. This tube provided 170 hits for step A of position 2. This value is the highest recorded among 97 tubes.

For each step of process, cumulated energy to cumulated hits ration (Rp) were calculated.

E1a: energy in position 1, step a (deformation).
N1a: hits in position 1, step a (deformation).
Rp1a: □energy /□hit in position 1, step a (deformation).

The presented data processing only concerns position 1 and 2 where probability of crack is higher (c.f. fig 6&7). These AE characteristics are entrance value of statistic study. Correlation plot can allow separating different kind of tube.

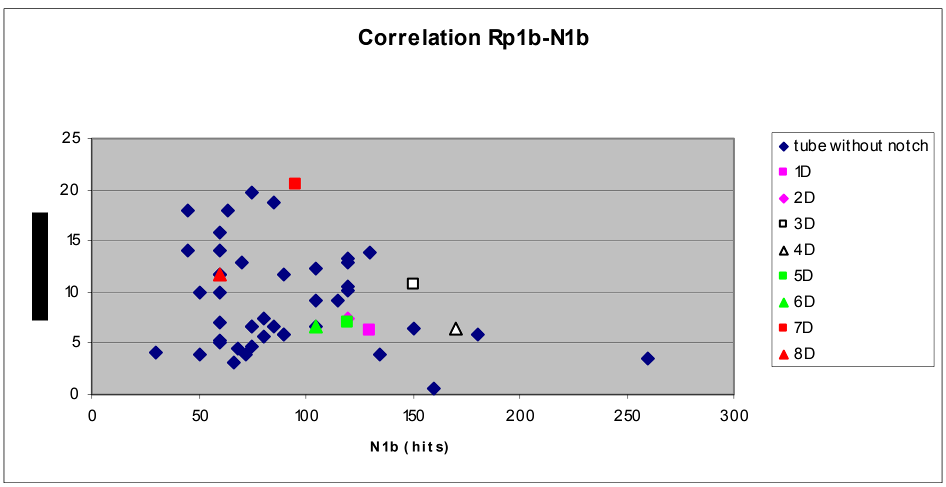

Figure 6: correlation plot Rp1b versus hits

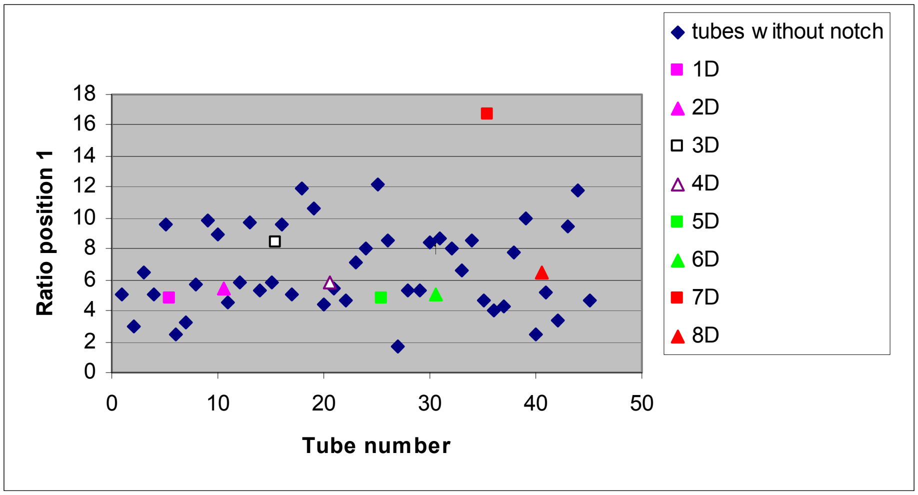

Figure 7: Rp1 calculated for position 1

- Notch on outside of weld seam:

Acoustic Emission detected for tubes 1D, 2D, 5D, and 6D don't allow identifying tube with artificial notch. Moreover same kind of tubes provides similar AE characteristics.

- Notch on inside of weld seam:

AE activity is different for tube 3D and 4D but not enough to distinguish tube with or without artificial notch. Therefore tube n°7D (notch 2/10 mm depth) is characterised by the highest Rp1b (ratio for expansion of tube ends) value among 53 samples. Tube 8D exhibits higher value of Rp1 than other configurations not enough to separate it too.

Figure 8: Picture of cracked tube.

It is important to point out that tests have been done with tube rotation according to weld position. That means notches on inside or outside of weld seam were located in the weakest stress area.

According that, separation of tubes with or without notch is possible only if notch grows during deformation. Visual inspections after process have confirmed there was practically no evolution of notch. Statistic analysis confirms that process of many tubes do not modify Acoustic Emission result too.

Conclusions:

A pressing machine has been instrumented with acoustic emission equipment. The environmental noises have been filtered out according to forming process and acoustic emission signal's characteristics. Analysis of pressing steps and the induced strain has been necessary to understand and insulate crack propagation phenomenon from ductile strain.

The potential cracking position has been identified in the complete process of forming. The tubes with the most severe artificial defects have been clearly sorted out during forming, even if it is difficult to verify by other technique if crack has actually propagated.

An abnormal shape can be easily detected in real time.

With these test results we can conclude that the industrialisation of acoustic emission in service monitoring could be achieved to detect problem during forming.

This real time technique can help to reduce the number of rejected tubes according to surface defect.
The feasibility study has to be extended to others machines. No installation has been programmed for the time being because our customer risk is guaranteed.
Before adjusting the final criteria of an automatic diagnostic, further statistical study has to be carried out to characterise reject percentage in association with the standardised fatigue test.

References:

[1] Process monitoring with Acoustic Emission. Non destructive testing handbook Vol. 5, ASTM
[2] Gervasoni, R. L'émission acoustique appliquée au contrôle des crémaillères de direction. 6ème ECNDT 24-28 oct. Nice 1994
[3] Tagushi: Experimental plan that enables us to test the effect and possible interaction of factors using a minimum of tests, by presenting the results in the form of a model.