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Acoustic Emission Studies in Hip Arthroplasty – Peak Stress Impact *In Vitro* Cemented Prosthesis

N. Gueiral and E. Nogueira
CIETI - Centre of Innovation in Engineering and Industrial Technology, ISEP - School of Engineering, Polytechnic of Porto Portugal

1. Introduction

Engineering has a very important role in the development of non-destructive monitoring of orthopaedical systems allowing the evaluation of its integrity.
Sir John Charnley revolutionized the field of joint arthroplasty in the 1960s with the development of the total hip replacement. He replaced the diseased hip joint with a steel femoral component and a plastic acetabular socket cup combination, both fixed into the bone using a self-curing acrylic cement, polymethylmethacrylate (PMMA) (Browne et al, 2005). That way, he has restored some of the most problematic joints in the human body.
The placement of the metal implant in the channel open in the femoral bone without using cement or by mechanical attack, called a non cemented arthroplasty, came into use in an effort to solve the problem.
A study about prostheses reviews, between 1979 and 2005, show that's were higher in non-cemented prosthesis, leading to studies on new forms of interface bone/metal. The growth of cemented arthroplasties has been observed since 2005.
By Ramos (Ramos et al, 2005), cemented arthroplasty is one of the most successful surgical techniques in orthopaedics. However, the cemented prosthesis has a tendency to fray during the time of their life due to stress and fatigue of the cement material leading to it cracking.
The growing importance of different Total Hip Arthroplasty (THA) studies is due to increased life expectancy of the population and its social and clinical relevance. Interdisciplinary THA studies such as: biomechanics (Bergmann et al, 2001; Fonseca et al, 2010; Nabais, 2006; Ramos et al, 2005; Stolk et al, 2006; Teixeira et al, 2008; Vieira, 2004); finite element analysis (Bachtar et al, 2006; Nizam Ahmad et al, 2006; Ridzwan et al, 2006) and acoustic emission monitoring (Browne et al, 2005; Cristofolini et al, 2003; Davies et al, 1996; Franke et al, 2004; Gueiral, 2008; Qi et al, 2005; Qi, 2000; Rowland et al, 2004) have been published.
Research has been done to improve the performance of artificial implants, addressing factors such as geometry, materials, cements, and other surgical techniques that directly or indirectly, might influence the performance and success of cemented arthroplasty.
Although the lifetime of a THA is between 10 and 15 years, there are factors that lead to loss of prosthesis such as the separation of the femoral prosthesis due to the splitting of connection between the implant/cement and cement/bone. The human body responds through its immune system causing inflammation and pain in osseous structure, which in most cases leads to the replacement of the prosthesis.

One the mechanisms of failure in total hip arthroplasty cemented prosthesis is the cement fatigue. So it becomes relevant to perform the monitoring integrity of these structure types (Gueiral, 2008).
It's important to have a technical solution capably reliable to indicate the time to have a replacement surgery. In this context the Acoustic Emission (AE) has a major role because it allows to determine and analyze cracks, microcracks and defects which can lead to delamination of cement and/or rupture of the connection implant/bone (Browne et al, 2005).
The monitoring of the structural integrity of cement and interfaces (implant and bone) by detection of acoustic emission waves, represents a significant advance in the assessment and inspection of the performance of cemented prosthesis, in relation to usual practice, which is the patient operation for prosthesis inspection.
It is in this context that fits the presented work on the AE acquisition and signal processing obtained *in vitro* fatigue testing in the femoral component, being of great importance to identify the location of the sources that originates it.
AE is certainly the most promissory method for orthopaedic diagnostic not only *in vivo* but also *in vitro*. This diagnostic preferably should include non-destructive methods without intrusion or radiation for the patient (Franke et al, 2004). AE studies have been done since 1990 in THA with different issues of evaluation of fixation parameters of prostheses, cement fatigue and others. The first studies *in vitro* of the prostheses metal/cement interface integrity with acoustic emission and ultrasound have been done in 1996 (Davies et al, 1996). Acrylics and synthetic cement studies appear in 2000 (Qi, 2000).
The results of different THA biomechanical simulation studies identified areas in an implant-cement and cement-bone that are subjected to greater stresses and strains (Fonseca et al, 2010; Nabais, 2006; Prendergast et al, 1989; Stolk et al, 2004). The AE technique is important to observe the impact of stress and strain, translated into microcracks, in the aforementioned areas in cemented hip prostheses as in interfaces implant-cement and cement-bone. So, AE monitoring better allows to understand the orthopaedic construction mechanisms and in focusing other mechanisms that were not detected by conventional ways.
According to Browne (Browne et al, 2005), signals of AE allows to study the fatigue behaviour of the cement that holds the implant to the bone in orthopaedic implants. With the fatigue test the mechanisms leading to the failure of an hip prosthesis are characterized.
The second part of this work characterizes the Acoustic Emission phenomena, considering the origin and propagation, parameters and detection of AE signals as well as modelling studies. The third part, describes the methods of AE sources location, in particular the 3D methods which are needed to study the hip arthroplasty *in vitro*. The fourth part describes *in vitro* experimental tests of femoral components with cemented prostheses. The last part contains the conclusions and final remarks.

2. Acoustic emission

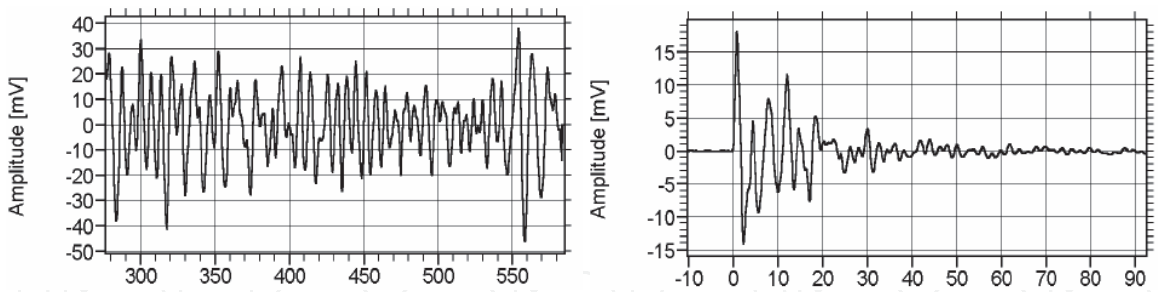
2.1 AE origin and propagation

Acoustic Emission belongs to the class of phenomena where transient elastic waves arising in the material are generated by the rapid release of small amounts of energy of the material (ASTM E1316, 2007).
These elastic waves are developed from an epicentre, commonly called AE source, and propagated indefinitely in all directions throughout the material and according to their characteristics will be attenuated until the total loss. We can liken the phenomenon to an earthquake, with due consideration of materials and proportions.

Acoustic emission wave propagation out of the source it generated over the structure is always a complex mechanical puzzle. Waves of different types propagate at different velocities and with different oscillation directions. Moreover, passing through a medium, waves undergo multiple changes due to attenuation, dispersion, diffraction, scattering, reflection from boundaries, interaction with reflections and other (Muravin, 2009).
The attenuation refers to the decrease in AE amplitude as a stress wave propagates along a structure due to energy loss mechanisms, from dispersion, diffraction or scattering.
The AE wave dispersion is caused by the frequency dependence of the speed of waves. Sound waves are composed of different frequencies hence for different frequency spectrums there are distint wave' speeds.
The spreading or bending of waves passing through an aperture or around the edge of a barrier is called difraction.
Scattering is the dispersion, deflection of waves when encounter a discontinuity in the material such as holes, sharp edges, cracks inclusions, etc.
Depending on the properties of each material, the response to the phenomenon will be different for external requests, such efforts, torsions, distensions and contractions.
One base theory to AE propagation is called Modal Acoustic Emission (MAE). It begins with the assumption that the AE waves are mechanical in nature, treating them as such. The general theory of wave propagation in solid media, says that AE waves propagate through a structure in a variety of modes with dispersion and attenuation characteristics. The separation of these modes in sensors can make possible to extract accurate information about the source that produces the wave. According to Jiao (Jiao et al, 2004) AE signals are in fact dispersive elastic waves.
The AE sources are usually manufacturing defects, minor cuts resulting from a defective welding, delamination, displacements, cracks, crevices and others. These AE sources only produce AE signals when subjected to new stresses, taking into account the Kaiser and/or Felicity effect. Thus, a possible source in the existing AE first time it is placed under the inspection sensors AE does not give any response because the source is asleep, i.e., need of higher efforts to generate new AE signals.
The number of AE sources in a particular structure depends largely on type of material that constitutes the structure. If the material is glass, ceramic or metal, the number of AE sources is low due to the crystalline structure of the material and the signal is well defined with relatively high amplitudes. If the material is concrete or composite it will increase the number of AE sources. On concrete, usually due to the porosity of the mortar there are a lot of AE sources whereas in composites these increase exponentially because just a short blow of the composite filament is enough to generate a new AE source. However, the amplitude is much lower compared with the AE sources in ceramic or glass.

2.2 AE signals: parameters and detection

Generally there are two types of AE signals which are represented in figure 1. One of them, a continuous signal is a qualitative description of the sustained signal produced by time-overlapping signals, figure 1a). The other one, a burst signal is a qualitative description of the discrete signal's related to individual emission events occurring within the material, figure 1b).
Each type of signal is related to the material under study/stretched. Porous materials or composites produce continuous AE signals. Ceramic or metallic materials produce signals AE burst.



(a) Continuous signal. (b) Burst signal

Fig. 1. ”AE Testing Fundamentals, Equipment, Applications” , H. Vallen

The electrical signal identified as an AE signal is generated by fracture phenomena. Therefore characteristics of AE parameters have been studied to infer fracture or physical phenomena. Signal parameters most widely used are explained from definitions (ISO 12716 2001):

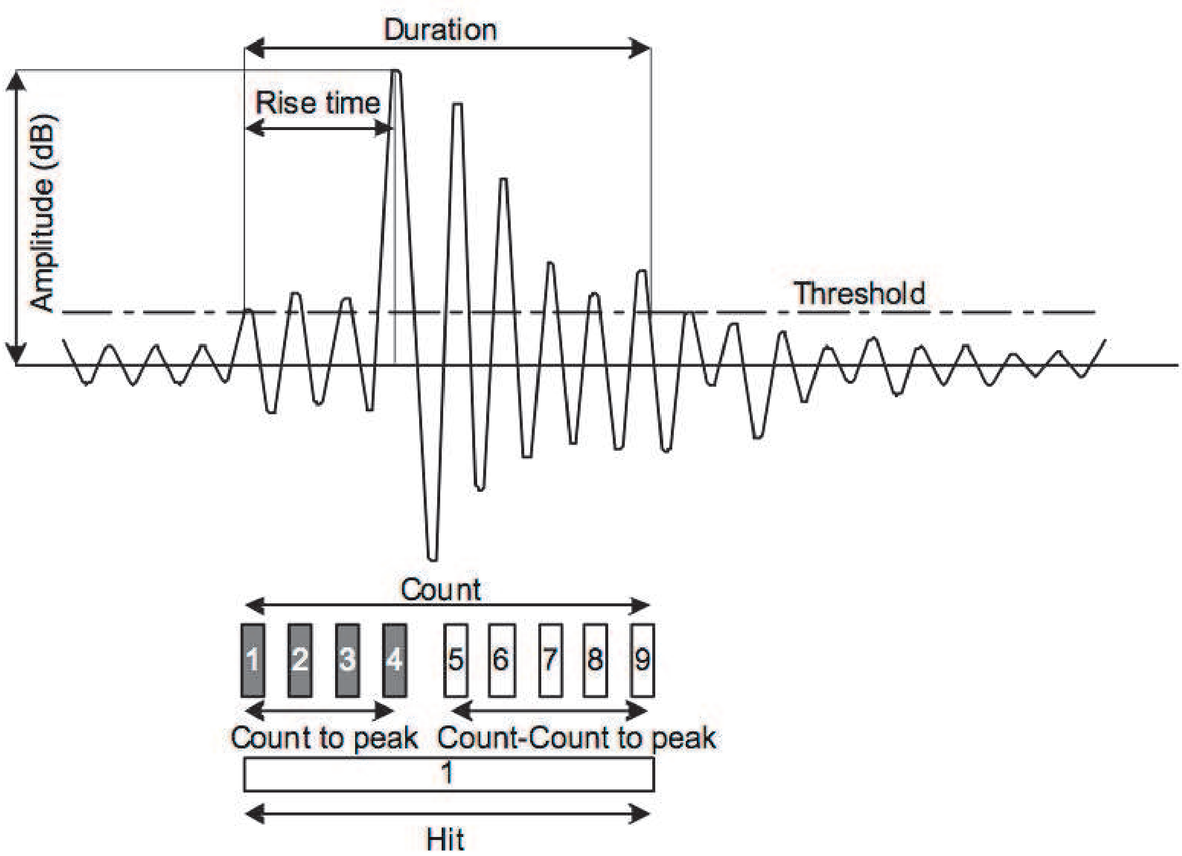


Fig. 2. Conventional AE signal features (Shiotani, 2008)

- *Hit:* a signal that exceeds the threshold and causes a system channel to accumulate data. It is frequently used to show the AE activity with counted number for a period (rate) or accumulated numbers. In figure 2, one waveform correspond one "hit".
- *Count/ring-down count/emission count:* the number of times within the duration, where one signal (waveform) exceeds a present threshold. In figure 2, nine counts are observed. "Count" is also employed to quantify the AE activity as well as "hit". It is noted

that "counts" depend strongly on the employed threshold and the operating frequency. Sometimes, counts between the triggering time over the threshold and the peak amplitude is referred to as "Counts to Peak", which is equal to four in figure 2.

- *Amplitude:* a peak voltage of the signal waveform is usually assigned. Amplitudes are expressed on a decibel scale instead of linear scale where $1\mu V$ at the sensor is defined as 0dB AE. The amplitude is closely related to the magnitude of source event. As mentioned the AE signals are detected on the basis of the voltage threshold, the amplitude is also important parameter to determine the system's detectability. Generally the detected amplitude shall be understood as the value does not represent the emission-source but the sensor response after losing the energy due to propagation. The magnitude of amplitude in each signal has been often analyzed in relation with frequency distribution.
- *Duration:* a time interval between the triggered time of one AE signal (waveform) and the time of disappearance is assigned. The duration, which depends on source magnitude and noise filtering is expressed generally in microseconds.
- *Rise time:* a time interval between the triggering time of AE signal and the time of the peak amplitude is assigned. The rise time is closely related to the source-time function, and applied to classify the type of fracture or eliminate noise signals.
- *Energy:* definitions of energies are different in AE system suppliers, but it is generally defined as a measured area under the rectified signal envelope. The energy is preferred to interpret the magnitude of source event over counts because it is sensitive to the amplitude as well as the duration, and less dependent on the voltage threshold and operating frequencies.

Before addressing specifically the process of detecting AE sources, it is of particular importance to observe the concepts and specifics of the AE system detection.
AE waves are detected by sensors, which convert dynamic motions at the surface of a material into electrical signals. Because AE signals are weak, they are normally amplified. The signal-to-noise ratio of equipments shall be low, and the amplifiers often provide more than 1000 times gain. Normally is set 100 times or so. The band-pass filter is successfully employed to eliminate the noises. In engineering materials, the band width from several kHz to several 100 kHz or 1 MHz is recommended in the measurement (Ohtsu, 2008).
AE signals emerge rapidly and randomly. As a result, the discrimination of AE signals from running waves is the first step for analyzing AE activity. To this end, the voltage threshold of AE wave, which is equivalent to a voltage level on an electronic comparator, is set. Then, the signals which exceed the voltage threshold are identified as AE signals (Shiotani, 2008).
The main purpose of AE sensors is to detect stress waves motion that cause a local dynamic material displacement and convert this displacement to an electrical signal. AE sensors are typically piezoelectric sensors with elements maid of special ceramic elements like lead zirconate titanate (PZT). Mechanical strain of a piezo element generates an electric signal. Besides PZT sensors, new types of sensors are under development. Other types of sensors include between others capacitive transducers and laser interferometers. Typical frequency range in AE applications varies between 20 kHz and 1 MHz. Sensors may have internally installed a preamplifier (integral sensors).
Selection of a specific sensor depends on the application and type of flaws to be revealed. There are two qualitative types of sensor according to their frequency response: ressonant and wideband sensors. Thickness of piezoelectric element defines the ressonance frequency of sensor. Diameter defines the area over which the sensor averages surface motion.

Another important property of AE sensors includes Curie Point, the temperature under which piezoelectric element loses permanently its piezoelectric properties. Curie temperature varies for different ceramics from 120 to $400C^o$. There are ceramics with over $1200C^o$ Curie temperature (Muravin, 2009).

2.3 AE process modelling

To understand the signals obtained by AE sensors it is necessary to model mathematically the whole AE process. The ability to accurately model acoustic emission process offers significant potential to improve the interpretation of AE data.

Applications of such models include the determination of optimal placement of sensors in an AE test, the scaling of AE results from laboratory coupons to structures of practical interest, the calibration of transducers, identify source mechanisms and insight into inversion of AE data to eliminate extraneous noise.

Several models of acoustic emission process, taking into account the application and the materials, are referred following. Source modelling (Hora, 2010); physicomathematical model of generation of AE (Belikov, 2008; 2010); crack grouth finite element modelling in plate structures (Wilcox et al, 2007); micromechanical model of microcrack formation in heterogeneous materials (Nosov et al, 2003) and AE waveforms modelling in thin plates (Prosser et al, 1998).

In the following text a more detailed description of these studies which are the best suited to the AE process of THA is made in *in vitro* system which consists of a femoral component with multiple layers of different materials (glass fiber reinforced - cortical bone, polyurethane foam - trabecular bone, cement and metal implant).

Hora (Hora, 2010) presented an acoustic emission source modelling by means of finite element method system COMSOL Multi-physics. Growth of cracks is an important AE source, and the study of the waves that they generate has played a major role in the understanding of the inner structure of the materials and the nature of the AE source. Energy release during growth of crack can be simulated by the concentrated force or concentrated force moment.

The kinds of the acoustic emission sources used in this paper, were the spatially concentrated force and concentrated dipole. The simplest problem corresponds to a spatially concentrated force (or point source) directed along one of the coordinate axes. The starting point is the scalar wave equation with a source term, which is first solved for an impulsive source, in which case the solution is known as Green's function for the problem. Then the Helmholtz decomposition theorem is used to reduce the solution of the elastic wave equation to the solution of two simpler ones.

This study aims to choose the best model of concentrated force and dipole. These models will be used to calculate the surface displacements in real steel constructions for the purpose of comparing that with surface displacements obtained by non destructive testing.

Belikov (Belikov, 2008) presented a physicomathematical model of generation of AE that is based on a system of average equations of heat and mass transfer in heterogeneous media (HM). The equation (1) describes the propagation of longitudinal and transverse waves in an HM consisting of a certain finite number of phases (Belikov, 2008; 2010). In the following expression ν represents the frequency that corresponds to vibrations of the interphase surface between two phases.

$$\nu = \sqrt{\frac{\Delta\tilde{\alpha}\Omega}{\rho\tilde{L}}} \tag{1}$$

$\Delta\tilde{\alpha}$ is the average difference of the elastic stresses at the interface between arbitrary two phases of the HM. Ω is the specific internal surface that corresponds to the internal surface S which separates the two phases, $\tilde{L}$ is the vibration amplitude of the interphase surface that corresponds to the contact between the two phases and ρ is the HM density.
The results of solving the direct problem, that is, constructing the AF spectrum using the relation of the AE frequency to the structural characteristics of a medium, allow to solve the inverse problem. This make the reconstruction of the characteristics of a damaged solid, including primarily the crack size distribution function using the observed amplitude - frequency spectrum of the acoustic emission. This algorithm was proposed by Belikov (Belikov, 2010).
A micromechanical model of acoustic emission of heterogeneous materials is presented by Nosov (Nosov et al, 2003). The model describes acoustic emission at the stage of delocalized microcrack formation that precedes crack formation or crack pop-in, relates fracture and elastic radiation parameters, shows directions for experimental studies and approaches to the development and modification of diagnostic methods.
Forecasting the fracture of structural materials is based on monitoring the damage kinetics. Of all non-destructive testing methods, this kind of observation can be carried out most successfully by the acoustic emission method. In this case, the time dependences and absolute values of the number of detected pulses, the type and parameters of the frequency spectrum of AE signals, the amplitude distributions of signals, the time intervals between pulses, etc., are used as data sources. The results of AE observations are generally interpreted in terms of crack growth mechanics, which does not allow micromechanical aspects of fracture and elastic radiation to be taken sufficiently into account and hence does not allow improvement in forecast accuracy.
The fine fracture relies on the statements of the kinetic failure theory, the micromechanics of fracture of solids, and the model that takes into consideration the number of AE pulses recorded at time t is directly proportional to the concentration of microcracks in a material. The acoustic emission coefficient (AEC) makes that direct proportion. Considering the stochastic nature of elastic radiation, the acoustic emission coefficient can be understood as the probability that the parameters of elastic waves coming from the AE source fall in the ranges of AE signal frequencies, amplitudes, and time intervals between the signals recorded by the measuring equipment.
The instability of AEC values during AE measurements breaks the similarity of fracture and elastic radiation processes, leading to errors in the evaluation of informative forecasting parameters and to a decrease in the forecast accuracy. This circumstance should be taken into account when processing primary AE data.
Wilcox (Wilcox et al, 2007) presented a modelling of the acoustic emission process in the crack growth in plate structures. The modelling framework referred as Quantification of Acoustic Emission Forward (*QAE-Forward*), is a forward model of the AE process from source to detection. The goal is to be able to simulate the time-domain signal that is received from a transducer when an AE even occurs anywhere in a structure.
This model was based on a modular linear system's architecture using frequency-domain transfer functions and was implemented within MATLAB. This modular architecture of *QAE-Forward* enables the source, propagation and detection of AE signals to be separated. The overall model for the frequency spectrum, $H(\omega)$, of a received time-domain signal, excluding noise terms, can be expressed as a single equation (2):

$$H(\omega) = \sum \left[E(\omega)P(\omega)BA(\omega)R_X(\omega) \prod R_C(\omega) \prod T_C(\omega) \right] \quad (2)$$

in which $E(\omega)$ is the modal excitability at the source, $P(\omega)$ is the delay due to propagation, $A(\omega)$ is attenuation, B is beam spreading, $R_X(\omega)$ is the sensitivity of the receiver, $\prod R_C(\omega)$ is the product of reflections coefficients of all features at which the ray is reflected and $\prod T_C(\omega)$ is the product of transmission coefficients of all features that the ray acoustic has traversed. The final received time-domain signal is the inverse Fourier transform of $H(\omega)$.

Such a model has a great importance for the development of AE-based Structural Health Monitoring (SHM) applications, because it can be used to optimize the spatial distribution of the sensors taking into account the sensitivity desired, to perform probability detection and false responses received by the sensors and to support cases based on the use of AE in a complex structures.

Prosser (Prosser et al, 1998) presented a study in which a comparison was made between two approaches to predict acoustic emission waveforms in thin plates. The geometries of many practical structures of interest for AE monitoring, though, are neither infinite in lateral extent, nor composed of thick plates or large components where propagation of bulk waves is dominant. Thin plates, pipes, shells, rods, and beams are common. In such geometries, the distance from the receiver to the AE source is often many times the specimen thickness and the wave propagation is dominated by guided modes.

A normal mode solution method for Mindlin plate theory (MPT) was used to predict the response of the flexural plate mode to a point source, step-function load, applied on the plate surface. The second approach used a dynamic finite element method (DFEM) to model the problem using equations of motion based on exact linear elasticity. This research has led to improved accuracy in the locating the sources of emission, better ability to discriminate and eliminate extraneous noise signals and enhanced identification of AE sources.

3. AE sources location

The main purpose of using an AE test is the detection, location and classification of the active source. The location of the source has been seen such as one of the benefits of using AE technique in different problems, in particular 3D methods which are needed to study the hip arthroplasty *in vitro*.

The location type depends on the geometry of the structure to be tested. If the structure's geometry is a little flat surface it is possible to locate a zone with one sensor. For pipes (cilindrical geometry) it is necessary two sensors to detect a plan and to detect a point source in a 3D structure geometry is necessary to use three or more sensors.

There is a variety of different location methods for different structural geometries and applications. One work about acoustic emission source location in dispersive media uses a non-iterative method with time-of-arrival (TOA) of several events received in an array of sensors arbitrary positioning in the 3D space (Lympertos et al, 2007). Complications arise, due to the dispersive, modal nature of ultrasound in most real structures and inhomogeneities in the wave propagation medium. The modal nature of the waves is countered by ensuring that the fastest mode is used at all times, but the inhomogeneities in the structure are less simple to overcome.

Moreover in composites materials, the wave speed along the fibre directions is faster than that perpendicular to the fibres due to the differing fibre and matrix material properties. In metallic engineering structures, where one would expect the wave speed to be constant in all directions, the geometry of the structure, thickness changes, holes, lugs, grease nipples, bearings and welds are only some of the features that dismiss the assumption that the wave propagation path from source to sensor is simple. In order to overcome this, Baxter

(Baxter et al, 2007) proposed the 'Delta T' method for locating AE events based on a set of artificial training data, generated by Hsu-Nielsen pencil lead fractures. Hensman in the paper "Locating acoustic emission source in complex structures using Gaussian processes" (Hensman et al, 2010) makes an extend to the work of Baxter.

Most of the location methods are based on evaluation of time difference between wave arrivals to different sensors. In the procedure of locating AE sources is essential to determine the arrival times of AE waves at different sensors (Jiao et al, 2004). In cases when time of arrivals is difficult or impractical to detect, other methods are applied. These include cross correlation methods for location of continuous acoustic emission signals or different zone location methods based on effect of signal parameters attenuation with a distance (Muravin, 2009).

In the procedure of locating AE sources, there are two typical options, a more traditional one based on the parameters of the signal and another that uses the Wavelet Transform (WT). Different authors demonstrated, that it is possible to extract accurately the arrival times of AE signals with the results of WT (Grosse et al, 2002; Hamstad, 2004; Hamstad et al, 2003; 2002; Jeong et al, 2000; Jiao et al, 2004).

More important information is possible to obtain from peak stress. Every peak stress corresponds to a larger number of AE events and a consequent larger release of acoustic energy. So it is possible to verify the existence of AE sources through energy studies. In study of Qi (Qi et al, 2005), the average energy for the crack follows the expression (3) where v represents the voltage AE (in nV) and t time:

$$Energy = U = \int |v| dt \tag{3}$$

The energy U is measured in eu (1eu = 1nV.s). In order to have a better understanding of the mechanism of defect-induced microcrack formation, the value of the slope of the energy-time (ET) relationship allows to divide fatigue process into three phases: initiation phase (ET > 0.6 - 0.8); transient phase (0.3 < ET< 0.8); and stable phase (ET < 0.3).

Based on the acoustic signal energy levels obtained, it is possible categorize microcracks into two types: type I and type II. A type I microcrack is a crack whose location is well defined because the AE signals from it are captured by four or more sensors. A type II microcrack is defined as one whose location is unknown because its energy/amplitude is so low that majority of the sensors are unable to capture it.

According Axinte (Axinte et al, 2005) methods to locate AE sources to three and two dimensions are based on triangulation sensors placed on different planes of the structure analysis such as shown in figure 3. In the figure 3 sensor S_1's position is considered the origin of axis system. That $x_1 = 0, y_1 = 0, z_1 = 0$ so $S_1(0,0,0)$. The intersection of three spherical surfaces centered on each of the sensors results in the point P whose coordinates define the location of source. Radius r is the distance between P and the sensor used as a reference system of axes. The radius of the spherical surface for each sensor is the sum of ray r with the path difference between that sensor and reference.

In the femoral component according to Gueiral (Gueiral, 2008; Gueiral et al, 2009) the calculus of source location was made by an analogy between the system used by Axinte (Axinte et al, 2005).

To quantify the failure mechanisms related to the loosening of cemented hip joint replacements were used techniques capable of monitoring nondestructively the initiation and progression of failure during *in vitro* fatigue tests.

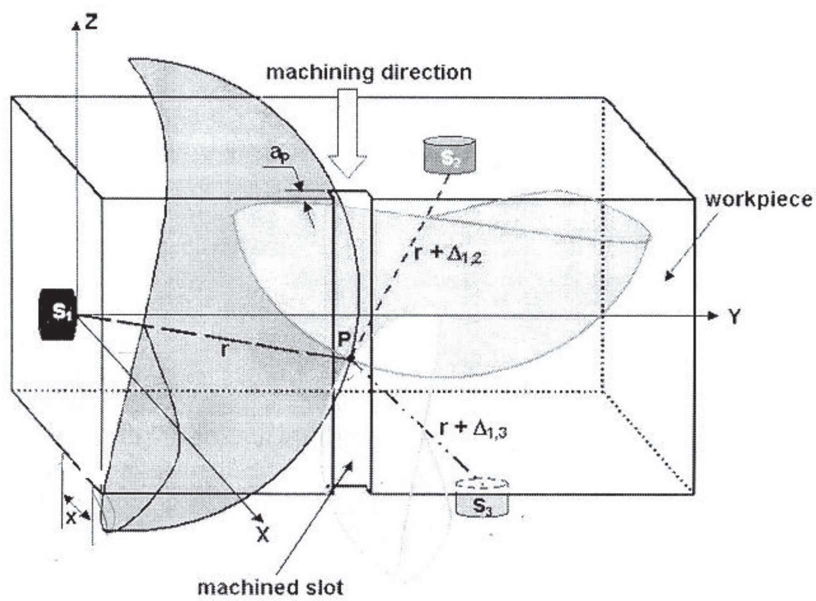


Fig. 3. Axis system and placement sensors (Axinte et al, 2005)

4. *In vitro* experimental tests of femoral component with cemented prostheses

A third generation in composite material, long left model 3306, femoral component by Sawbones was used in the study presented in the following text. The cement to fix the implant was CMW3 (polymethylmethacrylate with gentamicin) that is the most usual in cemented prosthesis.

The position of the femural component in the fatigue test to reflect the load on the THA to a certain amount of daily human activity was placed under the "femur coordinate system" defined by Bergmann (Bergmann et al, 2001).

The fatigue equipment was a pressure machine constructed according to the standards by an investigation group of Biomechanical Engineering which is part of the Mechanical Department of Aveiro University, Portugal. In the fatigue test the placement of the prosthesis in the testing machine follows the ISO 7206 standard (Qi, 2000; Ramos et al, 2005). The femur position was 9^o in sagittal plan and 11^o in frontal plan and was done by a base that supported the femoral component in the fatigue machine. The prosthesis fatigue test employed was done in accordance with (Ramos et al, 2005) being considered as the most severe by other authors (Cristofolini et al, 2003; Stolk et al, 2006). The sinusoidal charge cycles had a frequency of 2.5 Hz and 450 N in median amplitude. It was done between 900 N (minimum amplitude) and 1800 N (maximum amplitude). The femoral component under test had been constructed (prostheses collocated) about 3 years ago and it has been already used in a charge of 1 million of cycles and it does not present any visible crack. The test lasted 247343 s which corresponds to 618433 sinusoidal cycles.

Four sensors by Physical Acoustic Corporation (PAC) and Digital Wave Corporation (DAC) were mounted by a cylindrical distribution, as shown by Qi (Qi et al, 2005). The coordinates of the placement of sensors are presented in figure 4. To acquire the signals AE were used the AMSY5, Acoustic Emission System by Vallen.

The interface between sensors and femoral component was made by special synthetic silicon for polymers with excellent properties for the conduction of sound waves. Good collocation and attenuation (verified by Hsu Nielsen principle) essays were implemented to warranty a

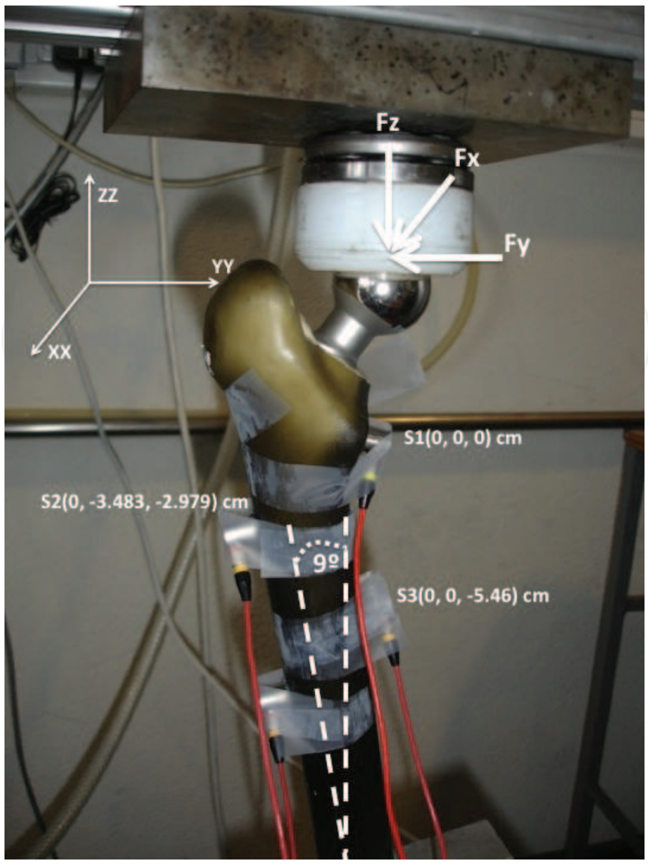


Fig. 4. Schematic placement of sensors and system of forces applied (Gueiral, 2008).

good signal AE acquisition. Usually tape-glue was used to sustain the sensors attached to femoral component.

During the process charge, sensor number 4 has been removed because it does not obtain any signal. After the charge we obtained three sets of AE events, the first appeared close to 7500 s (approximately two hours in fatigue), the second set of events appeared above 20000 s (approximately five and half hours in fatigue) and the third set of events appeared close to 55000 s (approximately fifteen hours in fatigue). Table 1 shows the acoustic energy during the component femural load process, that allows to conclude which of the events and which sensors have a peak stress, so an higher energy release. Analyzing the energy values in table 1,

Events	Sensor	Energy(eu)
1 (7500 s)	1	141×10^1
	2	331×10^2
	3	738×10^1
2 (20000 s)	1	155×10^1
	2	336×10^2
	3	814×10^1
3 (55000 s)	1	604×10^1
	2	127×10^3
	3	307×10^2

Table 1. Acoustic Energy

conclude that the femoral component was subject to maximum peak stress around the 55000 s, the third set of events. The sensor further "punished" is the sensor number two, because it presents a higher acoustic energy released as well as a larger amplitude measured by the sensor as we determine in the following analysis by WT.
To process the AE signal the WT software of Vallen was used to calculate the waves arrival times. That way, one could analyze all transients of acoustic emission signals and obtained really important information not possible with another analysis (Gueiral et al, 2009). Table 2 shows the obtained values for the wavelet coeffcient and arrival times to every set of events and to every sensors. The amplitude values have a permissible maximum error of 0.05 mV

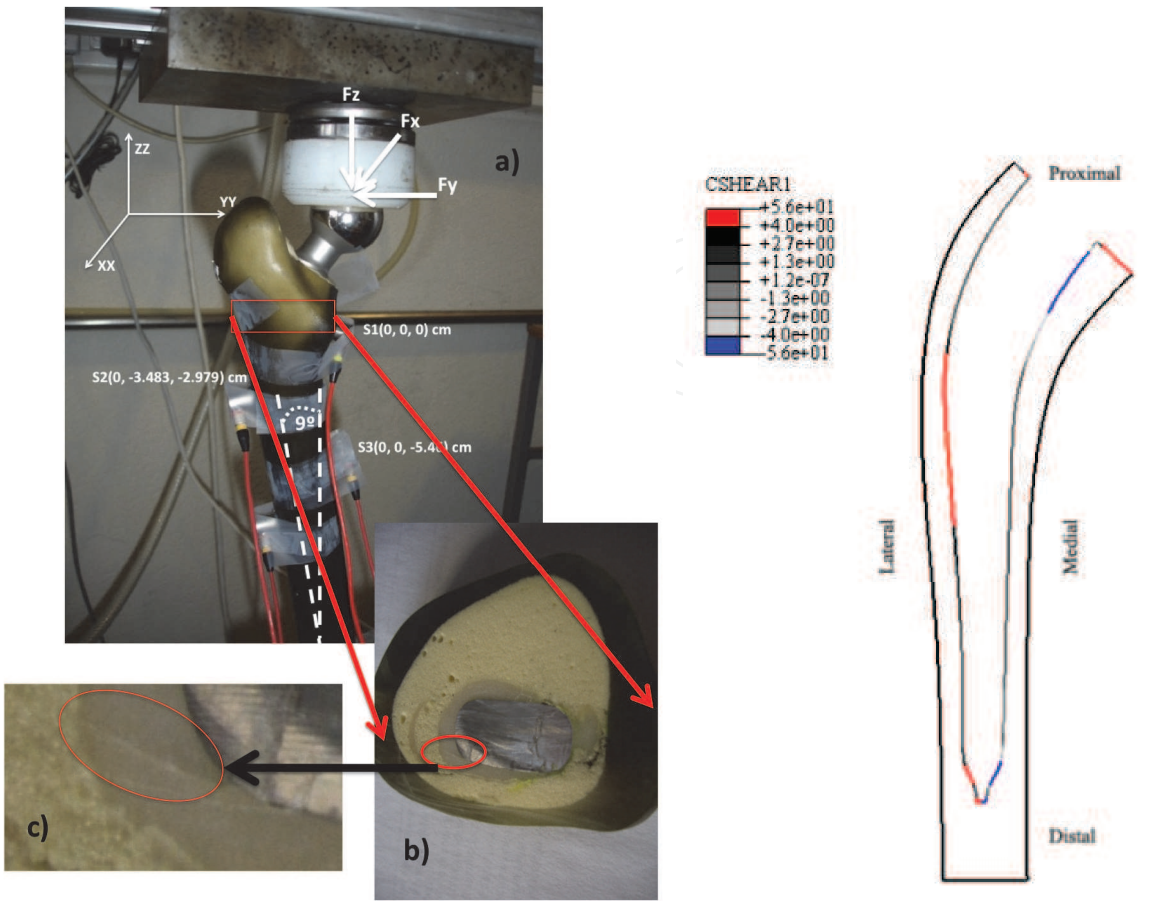
Events	Sensor	Amplitude(mV)	WT Coefficients	Arrival Time (μs)
	1	1.7	0.00210	11.5
1	2	7.0	0.00825	23.5
	3	3.5	0.00394	60.0
	1	1.7	0.00226	11.0
2	2	6.5	0.00842	24.0
	3	3.6	0.00401	60.0
	1	3.6	0.00426	13.5
3	2	13.0	0.01452	26.0
	3	6.5	0.00755	59.5

Table 2. Wavelet Transform data (Gueiral, 2008)

and 0.5 s for the arrival time. Observing the values in table 2 it is visible that the three sets of events happened at different hours of the charge cycle, but the arrival time is similar in every set of events. This analysis makes the possibility that a crack has occurred (source AE) in the femoral component. Another fact observed is that the amplitude rises from the second to the third set, this probably means that the crack spread from inside to the surface of the femoral component.
The amplitude in sensor S_2 is greater than in sensor S_1 and S_3, which indicates that the position of sensor S_2 is near the crack (source AE). The smallest arrival time is in S_1. So considering the above and the results according to Gueiral (Gueiral et al, 2009) shows that the most probable zone where it happened the crack is between S_1 and S_2.
Making restrictions in sensors positions (Gueiral et al, 2009) according to Axinte (Axinte et al, 2005) the AE sources location methods was made by iterative calculus and the real coordinates of AE source is presented in table 3. The sensor S_1 was considered the origin of axis system (figure 4). The femoral component was cut into sections to realize complementary diagnostic by liquid penetrant test and by optical microscopy (200x). The crack was located in the marked zone shown in figure 5a)-b) [with a crack zoom c)].
The finite element analysis in the field of orthopaedics has earned a privileged position in the use of numerical computational techniques applied to the evaluation of stresses and displacements in structural components. Some application of the finite element method in the field of orthotics make analysis of the mechanical behavior of bone and joints, as well as

Events	X(cm)	Y(cm)	Z(cm)
1(7500s)	-0.601	- 2.556	0.972
2(20000s)	-0.821	- 2.473	1.025
3(55000s)	-0.697	- 2.611	0.732

Table 3. Coordinates of the location of the source EA (Gueiral, 2008)



(a) Crack location in femural component (Gueiral, 2008) (b) Maximum shear stresses (Nabais, 2006)

Fig. 5. AE source location versus finite elements simulation

modelling of bone-implant failure. The displacement of the implant-cement interface and the failure of the implant-bone interface results in an increase of tensions in the cement mantle (Nabais, 2006).

According Nabais (Nabais, 2006), the maximum shear stress simulated by finite elements method are showed in the figure 5b). As one can see is really possible that the AE source detected in this study is located in the region of high stress concentration, figure 5b, when the femoral component is subjected to a fatigue test.

5. Conclusion

The monitoring of acoustic emission in evaluation structures integrity has the advantage to be done when the process is in charge, this does not happen in other non-destructives tests. That advantage is very important when one work with organic structures or organic substitution like in the study developed.

The signals obtained by the sensors system have the typical profile of a burst AE which means a good amplitude, duration and sufficient number of crossing the threshold.

The analysis of the acoustic emission results indicate the location coordinates of a crack in the structure, which coincides with the crack image observed in the optical microscope.

The surface metal prostheses have to be well polished because it may be the cause of cracking. As was observed in the microscopic images, in the local of the beginning AE crack formation, the metal implant had a sharp ridge.
In future work, given the constitution of the femoral component (different materials in thin layers) methods more stringent to locate sources should be used, not forgetting the fact that given the type of materials in question, the answer has a little number of AE events.

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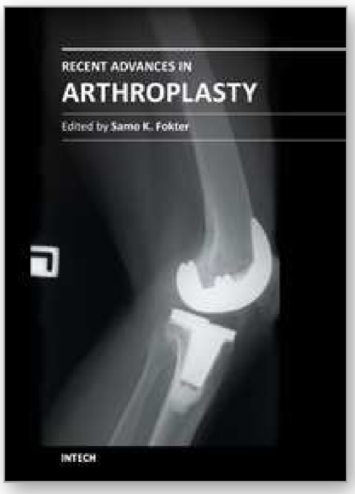

Recent Advances in Arthroplasty
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The purpose of this book was to offer an overview of recent insights into the current state of arthroplasty. The tremendous long term success of Sir Charnley's total hip arthroplasty has encouraged many researchers to treat pain, improve function and create solutions for higher quality of life. Indeed and as described in a special chapter of this book, arthroplasty is an emerging field in the joints of upper extremity and spine. However, there are inborn complications in any foreign design brought to the human body. First, in the chapter on infections we endeavor to provide a comprehensive, up-to-date analysis and description of the management of this difficult problem. Second, the immune system is faced with a strange material coming in huge amounts of micro-particles from the tribology code. Therefore, great attention to the problem of aseptic loosening has been addressed in special chapters on loosening and on materials currently available for arthroplasty.