Acoustic Emission Sensor Module

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***Abstract*—This paper presents a wireless acoustic emission sensor module with microcontroller for monitoring systems of structures under stress, prevailed by a piezoelectric AE sensor on the investigated material surface. The module performs the analogue/digital conversion of signals, the microcontroller commands the wireless interface, may send and receive information from other emitting - receiver wireless modules. The microcontroller could vary the amplifier gain and make the appropriate analogue / digital conversion. Many wireless modules with acoustic emission sensors could be successfully applicable to the AE monitoring systems of complex construction structures in the civil engineering, using a dedicated software.**

Keywords-AE; acoustic emission; non-destructive testing; NDT; μC; microcontroller

I. INTRODUCTION

Acoustic emission (AE) techniques [1] draw a great attention to the diagnostic applications, material testing and study of deformation, fracture and corrosion, because they give an immediate indication of the response and behavior of materials under stresses, intimately connected with strength, damage, fracture and failure. Also, AE technology involves the use of ultrasonic sensors (20 kHz - 1 MHz) to listen to the sounds of failure occurring in materials and structures.

The roughest localization method is guessing the source origin using the "first hit" technique. The advantage of first hit techniques is that no sensor arrays and no data analysis are necessary. The sensor which detects an AE first defines a radius or a half sphere, respectively, in which the signal originated. The utilizer's experience denotes whether that technique is accurate enough. This can be done for some cases in combination with other techniques or knowledge from bridge inspectors to "localize" the source of failures.

More sophisticated methods use planar techniques by recording AE signals at more than two sensors at the same time [2].

Also, 3D-Localization of acoustic emission [1] events is a powerful tool in quantitative AE techniques. Signal-based procedures, such as accurate 3D localization of damage sources, solutions for fault plane orientation, and moment tensor inversion, are applied in civil engineering. Other promising options are methods based on array techniques [3].

3D-Localization [4] of acoustic emission events is the basis of advanced signal interpretation and the discrimination between signal and noise. The more quantitative analysis of the signals is based on a 3D localization of AE sources (hypocenters) and the recordings obtained from a sensor network. Using moment tensor inversion methods, the radiation pattern of acoustic emission sources and the seismic moment (as an equivalent to the emitted energy) as well as the type (Mode I, Mode II, and mixed modes) and orientation of the cracks, can be determined [4].

During the long-term experiments of materials fatigue tests a great amount of signals, including the noises from the load-chain, can be detected by the sensitive AE sensors. According to the time sequence for the guard and main sensors to receive the signals, the signals originating from outside the test section can be detected and discarded.

Crack initiation is determined by the first appearance of the AE signal at low stress levels. This stage has a steady-state dislocation motion that will eventually result in microvoids and initiate microcracks. In the next AE-active stage cracks start to grow and propagate. Many AE signals can come from the crack-tip plastic deformation, fracture of hard inclusions, microcrack coalescence, transgranular cleavage, and fracture along grain boundaries, each producing an acoustic emission [5]. Ultrasound wave propagation in construction materials is presented in [6].

The structure of this paper is based on: 4 chapters, Conclusion and future work and References.

II. ACOUSTIC EMISSION TECHNIQUE APPLICATIONS

AE techniques have been widely used in the domain of non-destructive testing of material structures, such as: metal and composite pressure vessels for the local plastic deformation of ductile pressure vessels [7], [8], piping for locating the position and estimating the severity of leaks in pipeline networks [9], the detection of failures in various types of equipment in the petroleum industry (pressure vessels, tanks and pipelines) [10].

Also, AE generated during fatigue mechanism of steel was widely use as gas pipeline materials testing [11].

A new method to detect leakage in a water-filled plastic pipe through the application of tuned wavelet transforms to Acoustic Emission signals was proposed [12].

Acoustic Emission generated during fatigue mechanism of steel showed that AE Count gives a significant value during cyclic softening effect. Crack initiation was indicated by a rapid increase of AE count values at positive peak stress, followed by high AE count values around zero stress which indicated the crack closure phenomena [11].

Acoustic emission techniques (AET) are an alternative monitoring method to investigate the status of bridges or some of their components, because it has the potential to detect defects in terms of cracks occurring during the routine use of bridges [5].

Monitoring techniques based on wireless AE sensors for large structures in civil engineering [5] were developed, basing on a new kind of sensors using MEMS (Micro-Electro-Mechanical-Systems) techniques. These sensors should be intelligent, self-networking, asynchronous, wireless, adaptive, dynamically reprogrammable, cheap and small. The implemented wireless communication techniques will reduce the application and maintenance costs significantly [5].

Some techniques work as a maintenance monitoring system sending data (alarm data) via intranet to a data centre or alarm messages per SMS automatically to the monitoring engineer. Therefore, the public safety is assured as unseen structural damage is identified without costly and dangerous deconstruction.

Modern acoustic emission (MAE) techniques have applications in aviation industry, fully digital AE apparatus with low noise, high speed of data transmission and accurate AE source locating capability [13].

Acoustic emission techniques are an additional monitoring method to investigate the status of a bridge or some of its components. It has the potential to detect defects in terms of cracks propagating during the routine use of structures. However, acoustic emissions recording and analysis techniques need powerful algorithms to handle and reduce the immense amount of data generated. These algorithms are developed on the basis of neural network techniques and by array techniques [14].

III. NON-DESTRUCTIVE TECHNIQUE EXAMPLES

Some of AE application types are: **Crack detection, Fatigue testing** – collect data and give notification to a cyclic fatigue event occurrence in order to determine the plastic deformation, **Chip detection** - Detect the presence of a chip in a tool, also detect chipping as it occurs, **Tool Breakage Detection** - Instantly shut down a process when the tooling breaks, **Deep Drawing** – determine defects when they occur during drawing, stop draw press during "necking", **Stamping** - Determine **Good** vs. **Bad** stamping operation, **Piercing** - Indicate the presence of a missing or malfunctioning punch, **Scoring** - detect scratches and gouges as they occur in metal.

Nondestructive techniques were not accepted long time for the testing of bridges, and other components of the infrastructure because of two primary reasons: the difficulty in separating valid signals from extraneous noise and the inability of the AE technique to determine the size of the crack [15]. The acoustic emission (AE) signal can be divided into successive type signal and sporadic type signal, in order to be analyzed through the signal processor in the form of variables such as the existence of a signal generation or the shape of signal [1].

Locating of monitored fatigue cracks, destructive NDE technique has indicated that the first crack has run into a flange and the second crack is in both the weld and web and is growing at both ends. These cracks are referred to here as the "flange crack" and the "weld crack," respectively (Fig. 1).

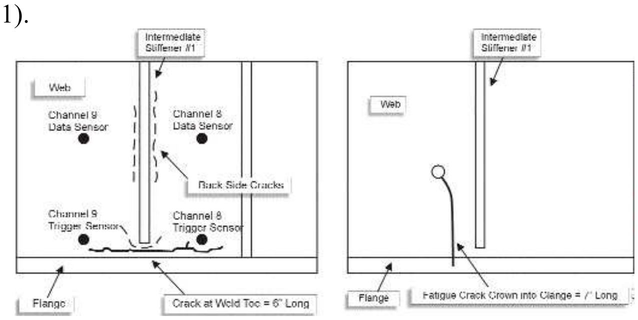

Figure 1. Example of location of fatigue cracks monitored [15].

In the location of fatigue cracks monitored experiment, it is confined only to the case that the direction of force is vertical applied to the surface of the test piece.

Other method of Acoustic Emission based on expert system for evaluating the structural integrity of the *metallic pressure vessels, spheres, columns and tanks* utilizes the Multichannel Acoustic Emission Systems and Sensors, which detect the high-frequency signals resulting from deterioration in the structure when the sample is stressed. The systems have sufficient speed and resolution to ensure real-time, on-screen indications of the development of any defects.

Structural health monitoring (SHM) deals with the more or less continuous recording of data obtained from several parts of the structure. Based on the experience of the constructor, owner, or inspector the damaged regions where data are obtained can be restricted and in many cases it is necessary to just detect a deviation of the "usual" behavior of the structure [14].

IV. EXPERIMENTAL MODULE

The AE sensor converts the mechanical vibration propagated through the material into electrical signal. The

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amplifier magnifies the electrical signal, making useful for the dedicated software. The microcontroller (μC), as the central unit of the module, commands the amplifier gain and makes the appropriate analogue – digital conversion

The sensor was designed to be used with an amplifier, of 40 dB maximum gain, which can be controlled by the μC.

The wireless acoustic emission sensor module with microcontroller for monitoring systems of structures under stress, processes signals received from a piezoelectric AE sensor on the investigated material surface. The module performs the analogue / digital conversion of signals, the microcontroller commands the wireless interface, may send and receive information from others emitting - receiver wireless modules. The microcontroller could vary the amplifier gain and makes the appropriate analogue/digital conversion. As remark, this module could be applied to complex AE monitoring systems of structures.

The experimental wireless module of acoustic emission sensor is composed by a piezoelectric AE sensor, a signal amplifier, a PIC 18F452 microcontroller (μC), a pair of emitting - receiver wireless modules (ES and RS wireless, i. e. TX2-433-5V and RX2-433-5V), and a whip antenna of 433 MHz. The block diagram of the experimental wireless module of acoustic emission sensor is presented in Fig. 2.

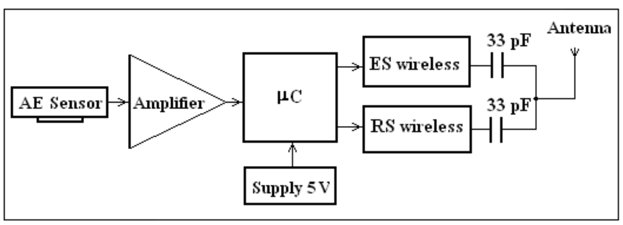

Figure 2. Block diagram of the experimental wireless module for acoustic emission sensor.

The output signal from μC is converted by the ES wireless module and transmitted in air by Antenna (433 MHz) to another antenna of 433 MHz (under the control of the monitoring system with μC) at distance. Also, the Antenna may receive signals from another antenna in order to command the μC and the amplifier gain of this wireless module (Fig. 2).

Three types of antennae for the wireless transmission module which could be used for RF propagation, namely: helical antenna, loop antenna and whip antenna (Fig. 3). For this experimental module, we have chosen the RF whip antenna of 15.5 cm length and 433 MHz work frequency.

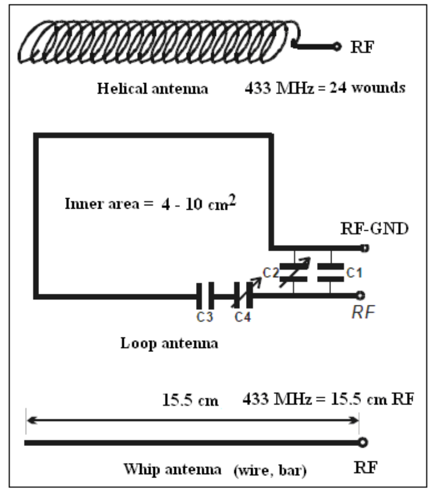

Figure 3. Three types of antennae for wireless module.

The piezoelectric sensor realizes the mechanical to electrical energy conversion, revealing the AE signals from the material samples, under mechanical stretches (Fig. 4). Mounting to the test specimen is typically achieved using silicon rubber or epoxy adhesives in order to realize the optimum electroacoustical transmission between the studied material and the sensor active surface.

Figure 4. AE piezoelectric sensor.

The main characteristics of some broadband AE piezoelectric sensors are presented in the Table 1.

TABLE I.

PROPERTIES OF SOME AE PIEZOELECTRIC SENSORS

Properties	AE sensor
Outer dimension	Diameter: 20.5 mm x 14 mm
Effective sensing area	Around 230 mm^2
Total mass (g)	12
Piezoelectric mass (g)	5 – 6
Capacitance (pF)	350
Piezoelectric charge coefficient d 31 (10^{-12} m/V)	-150
Frequency range (kHz)	100 - 450

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Figure 5. Experimental wireless module for acoustic emission sensor.

The experimental wireless acoustic emission sensor module with microcontroller for monitoring system has small size and is protected by a metallic case (Fig. 5).

Fig. 6 presents the AE signals prevailed by the sensor in the breaking moment of a concrete sample at the maximum stretch. A large data base, which contains information about different kind of construction materials (metals, concrete, rocks, minerals, etc.), referring to the AE signal parameters (amplitude, duration, number of pulses, etc.) could be then used in order to predict the material failure or the moment of the cracks initiation into material.

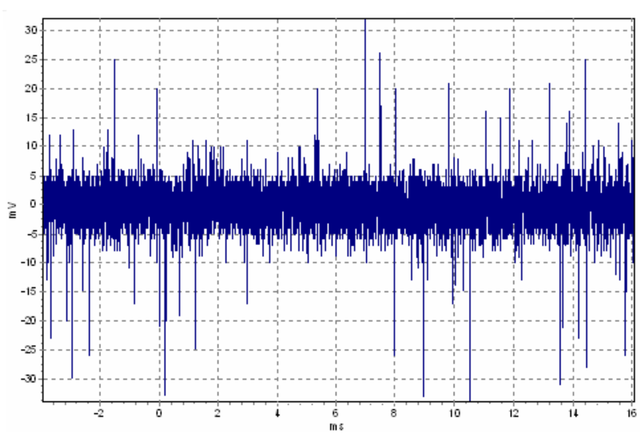

Figure 6. AE signals from a concrete sample at breaking point at mechanical stretch.

Also, the pulses calibration is necessary to be introduced to the test specimen under the control of the monitoring system. The generated acoustic signal is collected during the press or streched work. A preset filter ensures the optimum response from individual channel by matching the amplifier and transducer responses.

The ratio filtering techniques are used for eliminating outer noise signals, as well as observing the ratios of valid signals to estimate crack depth of the growing crack.

A digital memory oscilloscope type Tektronix TDS 2022 was used to the experimental researches. Fig. 7 shows AE signal converted by AE piezoelectric sensor, prevailed from an outstretched metallic bar and Fig. 8 present the processed signal from AE piezoelectric sensor by the microcontroller software, displayed on TDS Tektronix oscilloscope, which is limited at 2.0 V level.

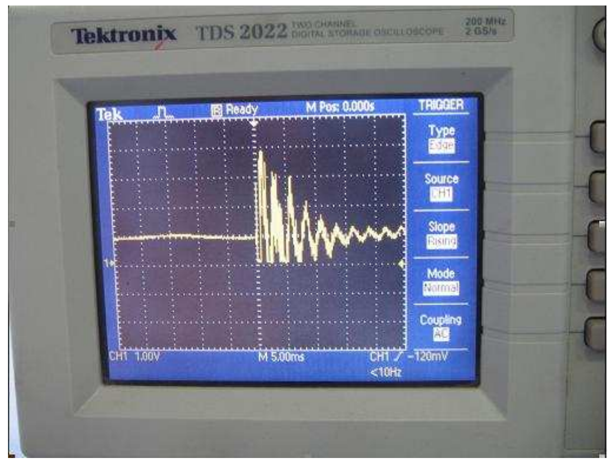

Figure 7. AE signal converted by AE sensor, prevailed from an outstretched metallic bar.

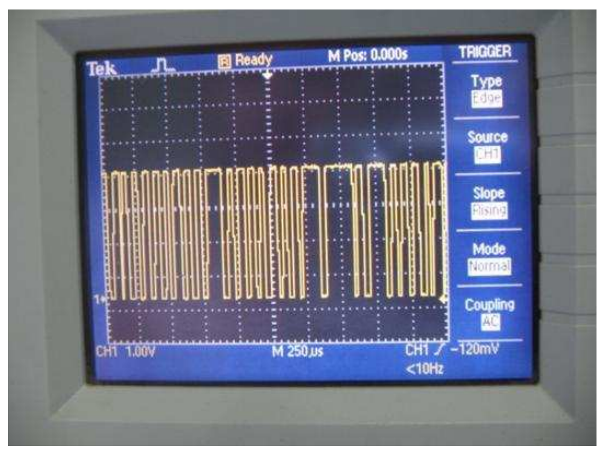

Figure 8. Processed signal from AE sensor by microcontroller software, displayed on TDS Tektronix oscilloscope.

The microcontroller software is able to realize the processing of signal received from the AE sensor, such as: the magnification in the case of a small AE level signal or to realize the sensor calibration, function of material characteristics (type, metal or nonmetal, acoustic velocity, density, structure, porosity, etc.).

For instance, we chosen to set the tension threshold at 1.0 V (above the reference line), in order to form the pulses, which exceed 1.0 V and correspond to the AE events, arisen in material under mechanical efforts (Fig. 8). The master system is positioned at 100 m distance from the wireless AE module. It collects all these pulses received from the wireless AE module, counts the number of these events and/or determines their duration. Further, this information can indicate the starting crash or braking into material or a possible irreversible material deterioration. This algorithm is preordained by the special software of PIC 18F452 microcontroller.

TABLE II. MECHANICAL PROPERTIES OF SOME METALLIC MATERIALS

Material	Longitudinal elasticity module, E, daN/cm^2	Transversal elasticity module G, daN/cm^2	Poisson Coefficient μ
Soft steel	$(2.0\text{-}2.15) \cdot 10^6$	$(7.8\text{-}8.5) \cdot 10^5$	0.24-0.28
Hard steel	$(2.0\text{-}2.2) \cdot 10^6$	$8.5 \cdot 10^5$	0.25-0.29
White wrought iron	$(1.0\text{-}0.6) \cdot 10^6$	$4.5 \cdot 10^5$	0.23-0.27
Tin	$0.2 \cdot 10^6$	$0.7 \cdot 10^5$	0.42

Table II presents some mechanical properties of metallic materials, which could be used in the specialized software data processing, as material constants.

CONCLUSION AND FUTURE WORK

Crack initiation of structures could be determined by the appearance of the AE signal at low stretch stress levels. After the crack initiated, the AE signals around the zero stress were thought to be caused by crack-face grinding when the cracks were closed. More experimental wireless modules with acoustic emission sensors could be well used into complex AE monitoring systems of important structures, such as bridges, buildings, metallic rails or underground. Inspection methods can be applied more efficiently by monitoring systems with many wireless AE sensor modules for large structures in the civil engineering. Next researches will be dedicated to obtain complex software around PIC 18F452 microcontroller, for controlling several AE modules of an AE monitoring system.

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REFERENCES

[1] D. H. Kim, W. K. Lee, and S. W. Kim, "Analysis of Acoustic Emission Signal for the Detection of Defective Manufactures in Press Process", World Academy of Science, Engineering and Technology, Vol. 53, pp. 1301-1305, 2009.

[2] ADVANCED ULTRASONIC FLAW SIZING HANDBOOK, 1998 Edition J. Mark Davis, DAVIS NDE, INC., http://www.ndt.net/article/1198/davis/davis.htm

[3] C. U. Grosse, Acoustic emission localization methods for large structures based on beamforming and array techniques, NDTCE'09, 2009

[4] C. U. Grosse, H. W. Reinhardt, and F. Finck, "Signal-Based Acoustic Emission Techniques in Civil Engineering", Mat. in Civ. Engrg., Vol. 15, pp. 274, 2003.

[5] C. Grosse, F. Finck, J. H. Kurz and H. W. Reinhardt, "Monitoring techniques based on wireless AE sensors for large structures in civil engineering", Proc. EWGAE 2004, BB 90-CD, Sept. 2004, pp. 843-856.

[6] I. Chilibon and S. Velizar, "Ultrasound propagation in asphalt", B.H.V. Topping and M. Papadrakakis, (Editors), Civil-Comp Press, Stirlingshire, Scotland, paper 91, Reference CST91, 10 pages, 2008.

[7] F. Rauscher, "Defect Detection by Acoustic Emission Examination of Metallic Pressure Vessels", Proc. EWGAE 2004, BB 90-CD, Sept. 2004, pp. 83-90.

[8] P. Tscheliesnig, "Corrosion testing of ship building materials with acoustic emission (AE)", Proc. EWGAE 2004, BB 90-CD, Sept. 2004, pp. 51-59.

[9] M. Taghvaei, S.B.M. Beck, and W.J. Staszewski, "Leak detection in pipeline networks using low-profile piezoceramic transducers", Structural Control and Health Monitoring, Vol. 14 (8), pp. 1063-1082, 2007.

[10] Z. H. Hanafi, N. Jamaludin, S. Abdullah, M. F. M. Yusofd, and M. S. M. Zain, Acoustic emission study of corrosion fatigue and fatigue for API 5L X70 gas pipeline steel, Applied Mechanics and Materials, Vol. 138-189, pp. 635-639, 2012.

[11] M. F. M Yusof, C. K. E Nizwan, N. Jamaludin, and S. Abdullah, "Acoustic emission behavior during fatigue crack of API5LX70 gas pipeline steel", Applied Mechanics and Materials, Vol. 80-81, pp. 148-152, 2011.

[12] M. Ahadi and M. S. Bakhtiar, "Leak detection in water-filled plastic pipes through the application of tuned wavelet transforms to Acoustic Emission signals", Applied Acoustics, Vol. 71, 634–639, 2010.

[13] R. Geng, "Modern acoustic emission technique and its application in aviation industry", Ultrasonics, Vol. 44 Suppl 1, e1025-9, Dec. 2006.

[14] C. U. Grosse, M. Krüger, and S. D. Glaser, "Wireless Acoustic Emission Sensor Networks for Structural Health Monitoring in Civil Engineering", ECNDT 2006 - Tu.1.7.3, 2006, pp. 1-8.

[15] S. Uppal, D. Yoshino, and H. L. Dunegan, "Using Acoustic Emission to Monitor Fatigue Cracks on the Bridge at FAST", Technology Digest, February 2002.