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The Appliction of DIC and AE Methods

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Abstract

In this work, the fundamental definitions and principles of application of Acoustic Emission as a method of SHM are elaborated. This includes: Recommended terminology and definitions of SHM by the AE method. Outline of recommended process of AE SHM. Fundamental assumptions and principals regarding development of new SHM procedures, selection of equipment and methods of data acquisition and analysis, diagnosis, monitoring and prediction by AE SHM. The developed principals provide an outline for systematic and standard development of new SHM applications based on Acoustic Emission method.

This paper presents, Knowledge of the ways in which cracks are created and propagate within the material is a key aspect of understanding. The Paper mainly focuses on piezoelectric system of sensors, and Measurements of crack propagation in structures for Non-destructive Evaluation Systems. It introduces concepts from the very basics and leads to advanced modeling (analytical/ numerical), practical aspects (including software/ hardware issues) and case studies spanning civil, mechanical and aerospace structures, including bridges, rocks and underground structures. In DCM Sample is photographed using a high-resolution digital camera mounted on an optical microscope. The resulting displacement information reveals the average motion present from the Centre of each of the small sub images used in the analysis, relative to the original position. It uses image processing to go from several images of material, and to then calculate the deformation at any point in the field, and to then find crack propagation and strain values.These results show a great application potential of the DIC technique for various situations such as inspectingshrinkage-induced cracks in fresh concrete, masonry and reinforced concrete structures, and safety of bridges.

Keywords: Acoustic emission, Structural health monitoring, Flawand Fault detection, Identification, Location, Assessment and monitoring, Crack propagation, Digital image correlation method.

1. Introduction

Structural health monitoring is an emerging field of engineering that deals with development and application of approaches for on-line assessment and monitoring of structures [1, 2, 3]. Safety and commercial needs are primary motivations behind SHM development. Safety motivation Analysis of failures in different industries over the world showed that proper design, selection of materials and construction do not necessary guaranty safety of structures in a long term. This is because structures can be subjected to extreme loads and harsh environmental conditions during their operational life. Material properties may degrade significantly over the time. Also, statistics of failures show that periodic non-destructive examinations of structures are not enough to prevent possible failures due to: Their statistical local application on a small portion of a structure.Toolarge re-inspection intervals, Limited monitoring capabilities, Inability to distinguish developing and non-developing flaws. Therefore, in order to reduce a risk of unexpected failure, it is necessary to develop methods capable of performing on-line, outage independent, global assessment and monitoring of structures. Commercial motivation another driving force behind SHM is a commercial need to develop methods that can provide measurable, quantitative criteria for condition-based maintenance. CBM is a relatively new approach being adopted in different industries that defines maintenance schedule based on the condition of structure. In other words, maintenance is performed whenever and wherever is necessary, allowing cost effective operation, minimizing need in outages and reducing risk of failure. Structural health monitoring vs. non-destructive testing Structural health monitoring is applied non-destructively and in many cases incorporates different non-destructive evaluation (NDE) methods.

2. Acoustic Emission and Structural Health Monitoring

Acoustic emission method fits uniquely to the concept of structural health monitoring due to multiple phenomenological advantages. Particularly, it can be used for: Diagnostics of overall structural integrity including detection, location, identification and assessment of flaws/faults during normal operation of a structure [4].Continuous or periodic monitoring. Identification of operation conditions that cause flaw/faults origination and development. Below, we elaborate fundamentals of structural health monitoring by the Acoustic Emission method, which include terminology and definitions, fundamental assumptions and standard process of SHM.

3. The Process of Structural Health Monitoring

The process of structural health monitoring can be divided on the following typical stages:

3.1 SHM procedure development.
3.2 Sensing.
3.3 Diagnosis.
3.4 Monitoring., E. Prediction.

3.1 SHM Procedure development

The first stage of procedure development is dedicated to collection of all necessary information regarding the structure, its design and materials, operational conditions, statistics of failures and etc. In addition, laboratory and/or full scale tests are conducted on structures with known flaws/faults at known stage of development in order to develop ability to detect, identify and assess specific flaws/faults in goal applications.

3.2 Sensing

Sensing is a process of data measurement. It involves measurement of AE as well as parametric data like pressure, temperature, strain and other according to the developed SHM procedure. There are several important aspects to address during the sensing stage. First, it is important check that data collected during data acquisition process is valid and can be satisfactory used for the purposes defined in the developed SHM procedure. If this is not a case, additional measurements with different setup or loading, operational and/or environmental conditions may be required. Second, during the sensing process, an express evaluation of a structure is normally performed to identify or rule out possible major conditions that may threaten the structure immediately or in a short term.

3.3 Diagnosis

Diagnosis is one of the primary goals of SHM. It effectively distinguishes a typical AE NDE from AE SHM. The objectives of diagnosis process are not only to detect and locate flaws/faults as in typical NDE but also to identify and assess them. To achieve these objectives special development efforts are required including material research, numerical modeling, and small or full scale samples tests. Diagnosis performed based on collected data using methods of statistical pattern recognition. Numerical modeling, analysis of stress conditions, history of the inspected structure, local application of different NDE methods, material investigations and other may be required to crystallize the most correct diagnostic picture of the condition of an examined structure.

3.4 Monitoring

Monitoring performed to follow over condition of a structure over time. It is performed periodically or continuously depending on the particular application. For success of monitoring it is necessary to identify quantitative and/or qualitative AE characteristics that are changing with flaw/fault development. Important goal of monitoring is to identify conditions causing flaw/fault origination and development in the inspected structure. Examples of such conditions are fatigue, mechanical and thermal overstresses, and etc.

3.5 Prediction

The goals of prediction are to: Identify the useful a remaining lifetime of structure. Define an appropriate re-inspection/monitoring policy based on diagnostic and monitoring results. Provide information necessary for CBM decisions. Prediction normally done based on diagnostic results, several monitoring and in conjunction with all information about the structure, its history and all know measurable or non-measurable risk factors.

4. Fundamental Assumptions of AE Structural Health Monitoring

Structural health monitoring by the AE method as any other scientific concept is based on a set of fundamental assumptions that are normally self-evident and not necessary have to be scientifically proven. The role of assumptions is to define a systematic basis of a concept or theory. Based on the author experience in the fields of AE, fracture mechanics, material science, physics of solids, a set of fundamental assumptions of SHM by the AE method was elaborated. It cannot be claimed at this moment that this set of assumptions is complete and thus further modifications and corrections could be required.

5. Digital Image Corrilation

The Digital image correlation was developed in the early 80’s at the University of South Carolina to measure full-field *in-plane displacements* and *displacement gradients* of a strained body at the macro scale. Digital image correlation is computer based process to obtain 2-D full field information by recording deformation and motion of speckle patterns on a specimen surface before and after deformation of the body. It takes advantage of the fact that applied stresses change both the thickness and optical properties of materials, to determine displacements and crack propagation in concrete structures. In this regard, one of important tool is digital camera. *Camera* with CCD array (has small photosensitive cells and high pixel count) records intensity of light falling on a pixel. Array in high resolution camera is rectangular with thousand or more pixels per line and a thousand or more lines per image. (3x3 pixel) Signal from CCD array is digitized and gives a reading of the light intensity for each pixel. Intensity readings are shown as 0 from dark pixels and 100 for light pixel (Grey Scale). Storage of image into pixel and combination of pixel is called *convolution*.Sensor is an array (rows and columns) of light-sensitive semi-conductors called pixels. Each pixel emits electrons when hit by photons. Number of electrons is proportional to the number of photons (amount of light).

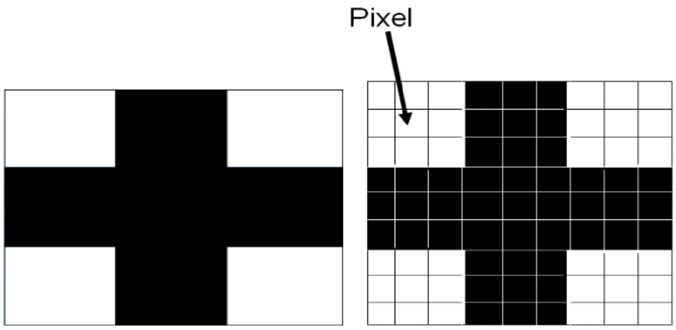


Fig. 1: Sub pixel image.

Digital Image Correlation (DIC) is a full-field image analysis method, based on grey value digital images that can determine the contour and the displacements of an object under load in three dimensions. Due to rapid new developments in high resolution digital cameras for static as well as dynamic applications, andcomputer technology, the applications for this measurement methodhas broadened and DIC techniques have proven to be a flexible and useful tool for deformation analysis.

Fig. 2: Gray Scale Images.

Each pixel is stored as a byte of memory. Byte values range 0 to 255 (256 scales of gray).For example a 640 x 480 gray scale image requires over307,200 bytes (over 300 KB) of storage. Image is stored in the computer as a matrix of gray-scale values. It can divide the matrix in to subsets and calculates the displacements of all subsets. Differentiate the displacement data to calculate the crack propagation in structure.

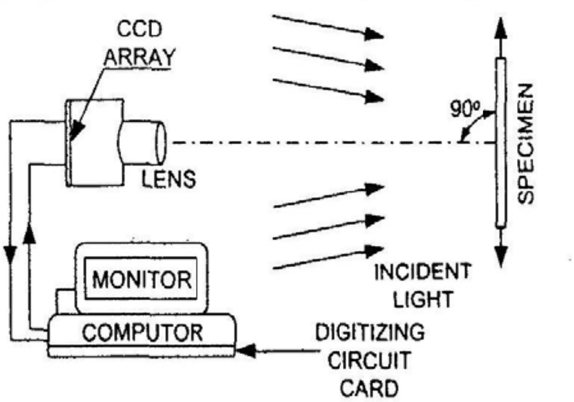
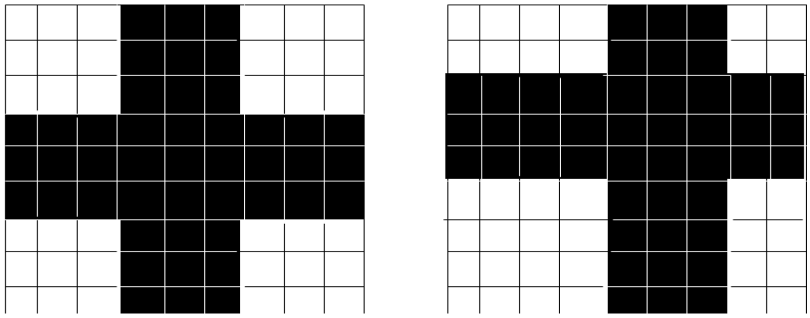


Fig. 3: Setup for DIC.

It is less demanding optically-ordinary incoherent light is sufficient and no need for optical components. Mainly it requires one Hi resolution camera for 2D displacement and for 3D displacement, also this experiment requires a computer and frame grabbing circuit card to digitize the output as shown in Fig.3



100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100

100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100

Fig. 4: Initial and final pixels before and after applied the loads.
Compares reference image to deformed image.

It is very simple in concept. Digital camera takes picture of surface of the specimenImage is downloaded from camera to a frame grabbing circuit card. Analog signal from CCD array are then digitized. The data is stored for subsequent processing. Surface of specimen is sprayed with target pattern. This is photographed before and after specimen is deformed. Digital image of specimen contains intensity measurements at each pixel location on CCD (*charge couple device-sensor*) array before and after. Using target features and their location, displacement field is generated. Accuracy upto 0.02 pixels has been achieved. It tracks the gray value pattern of subsets and calculates the displacement and cracks of all subsets.

$$\begin{aligned}
&(100-0)^2+(0-0)^2+(0-0)^2+(0-0)^2+(100-0)^2+\\
&(0-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(0-0)^2+\\
&(0-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(0-0)^2+\\
&(0-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(0-0)^2+\\
&(100-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(100-0)^2=18{,}000
\end{aligned}$$

At the center pixel,

$$C(5,5,-2,-2)=0$$

100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	**0**	0	0	0	0
0	0	0	0	0	0	0	0	0
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100
100	100	100	0	0	0	100	100	100

Fig. 5: Initial at zero displacement.

100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	**0**	**0**	**0**	0	0	0	0
100	100	**100**	100	0	0	0	100	100
100	100	**100**	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100
100	100	100	100	0	0	0	100	100

Fig. 6: Displacement at C(5,5,-2,-2).

$$\begin{aligned}&(100-0)^2+(0-0)^2+(0-0)^2+(0-0)^2+(100-0)^2+\\&(0-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(0-0)^2+\\&(0-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(0-0)^2+\\&(0-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(0-0)^2+\\&(100-100)^2+(0-100)^2+(0-100)^2+(0-100)^2+(100-0)^2=18{,}000\end{aligned}$$

$$I(x,\ y)=A+Bfx+Cfy+Dfxfy$$

where fx & fy are the fractional part of x & y

$$A=I(ix,\ iy)$$

$$B=I(ix+1,\ iy)-A$$

$$C=I(ix,\ iy+1)-A$$

$$D=I(ix+1,\ iy+1)-(A+B+C)$$

where ix & iy are the integer part of x & y

6. Results

DIC is a non-contact method for measuring whole field displacement. Method involves interpolation to smooth gray scale levels and then applies coefficient to map the parameters to find strains. Mathematics involved is challenging, but if computer code is available, mapping process becomes automatic. Accuracy is often quoted as ± 0.02 pixels for each displacement component. Accuracy depends on: - 1. Interpolation schemes, 2. Lens distortion, 3. Uniformity of light distribution, 4. Quality of speckle pattern. After verifying the performance of the software, the analysis of concrete structures is carried out. The surface of the sample is marked with black and white paint. The image before applied the load is registered by a digital camera. Then the sample is compressed to the crack propagating. The images at strains are also registered by the digital camera. Then the analysis of the strain and crack with the help of developed software is carried out.

Calibration: The quality of the measurement relies on exact know-ledge of the intrinsic and extrinsic parameters of the system. The calibration is easily done by taking images of a calibration panel under different perspective views. A bundle-adjustment algorithm calculates the in-transit parameter (focal length, principal point, distortion parameter) for each camera and their respective orientation, as well as the extrinsic parameter (translation vector and rotation matrix).

7. Conclusions

In this work, the fundamental principles of the structural health monitoring by the Acoustic Emission method were elaborated and discussed. This includes terminology, standard process of AE SHM and fundamental assumptions. The proposed fundamentals can be used for systematic development of new AE SHM procedures and applications. The resolution and application of the digital-image-correlation techniques are demonstrated in this report. The results show that the how crack propagating from one place to another place during applying loads. Using our self-developed method, one can calculate the stresses, strains and also crack variation in concrete structures and the deformation evolutions can be visualized by means of the digital-image-correlation technique.The identification of crack development in structures forms an important study for investigating the earthquake resistance capability of the masonry structures. Traditionally, inspecting the structure and documenting the findings were done manually. The procedures are time-consuming, and the results are sometimes inaccurate. Therefore, the digital image correlation (DIC) technique is developed to identify the strain and crack propagation. This technique is non-destructive for inspecting the whole displacement and crack field.

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