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THE CURRENT TRENDS IN STRUCTURAL HEALTH MONITORING IN AEROSPACE APPLICATIONS

Diana CAZANGIU[1], Ileana ROSCA[2]
[1] Transilvania University of Brasov, Brasov, ROMANIA, e-mail: cazangiu.diana@unitbv.ro
[2] Transilvania University of Brasov, Brasov, ROMANIA, e-mail: ilcrosca@unitbv.ro

Abstract: *This paper presents some general aspects about a new technique used, in aircraft industry, for determining the state of structural health.*
The Structural Health Monitoring method supposes the detailed observation of a structure using intelligent sensors, a performed acquisition system and a smart algorithm for data processing, the extraction of the damage feature and finally the statistical analysis of these data.
An optimum SHM system should be able to indicate the damage type, its location and to predict the residual life of a specific structure.
There are presented some current sensing method used in SHM systems for the aerospace applications. Also, it is shown the basic principle for the developing a smart algorithm for SHM systems and the two assumptions that were lead to the introduction of this new monitoring method in aerospace and civil area.
Keywords: *SHM, strain gauges, life prediction, damage detection*

1. INTRODUCTION

As a definition, the Structural Health Monitoring (SHM) is a new method which offers a prediction of the health state of the constituent materials of the structure. This structure health state can be altered, during the time, because of different factors, as: the fatigue of the materials structure, the environmental parameters or the accidental events. Applying SHM systems it can be determined the damage that occurs inside the material, its accurate location, the speed of the damage propagation and, finally, it can make a prognosis of the residual life of the structure.
With the help of smart sensors network placed on the surface or inside the structure it can be monitored the external impacts, it is possible to measure the strains and to detect the damage that occurred inside the structure. In parallel with the damage detection process, it can achieve the information from the environmental parameters. All these information that are stored in a specific storage sub-system, are processed, using an intelligent algorithm which takes account of the knowledge based on the fracture mechanics laws and on signal analysis methods. In this way, it is possible to predict the health state of a structure [1].
The SHM method can be applied in automotive and in aerospace industry, but it can be successful applied in civil area. In aerospace industry, at global level, the SHM method was studied from the beginning of the 1990s [1].
SHM is based on a non – destructive evaluation method which helps at the examination of the structure for damages. In the aircraft industry, there are a lot of testing standards but related to SHM method there is no available standards.
Through the main advantages of this method, it can identify:

- using SHM systems it is possible an optimum use of the structure, the reduction of the damages occurrence and the avoiding of the catastrophic phenomena;
- SHM method allows the replacing of the periodical maintenance inspection of the structure, made by human factor, with the automated embedded maintenance systems (that is on a long term);
- it allows the reduction of the involving of the human factor and, consequently, the human errors, improving the reliability and the safety of the structure.

In this paper it presents some aspects regarding the importance of the applying of the SHM method in aerospace applications.

2. THE MAIN ASSUMPTIONS OF SHM METHOD

In the recent years, the applying of SHM systems had an increasingly application in the aerospace industry.
SHM is expected to be one of the technologies for controlling the structural integrity of future aircraft, providing both maintenance and weight saving benefits.
The increase of the structure safety was a main assumption that determined the introduction of SHM systems in the aircraft structures. In the literature [1] it is specified that 4 % of the aircraft accidents it occurs because of the wear of the structures. The wear is a process that it happens during the time and it is produced by the fatigue of the materials structure.
The fatigue of the material [2] is a phenomenon that occurs in material under cycling loading at stress level much lower that the last stress of the material. The fatigue damages are presented in the form of very small cracks that can lead to the imperfections in material.
When is made a prediction of life structure based by the results of SHM systems it is very important to take account the environment parameters and the loadings of a studied structure. For example, in aerospace application, it needs to know very well the environment parameters (the temperature, the humidity and the pressure) that are developed in a real flight. Also it is good to know the loads which are involved under the structure during a specific flight mission. The loads are determined by different flight maneuvers (such as landing, take off, flaps down and turning) and by the side effects of the accidental events (at the military aircraft).
A second main assumption of applying of SHM method was the economic one. Related to Figure 1 it can observe that using SHM Systems for the structures the maintenance cost decreased, instead the reliability of these structures increased. For the structures without SHM systems it can see that the both factors (the maintenance costs and the reliability) were constant.

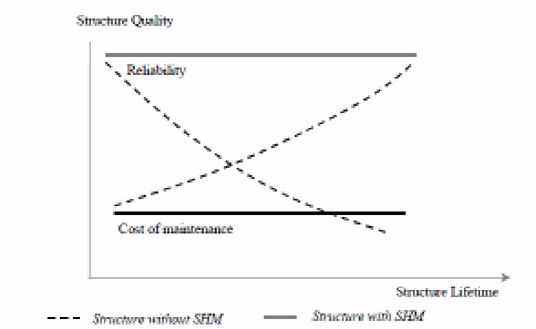

Fig. 1 The benefits for applying SHM systems at the structures [1]

A principle of SHM system function was proposed, in 2007, by Worden and Manson [5]. This principle was simple represented by an organizing scheme, called "Waterfall model", that is showed in Figure 2.

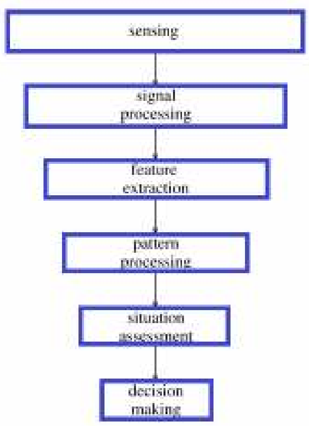

Fig. 2 The Waterfall model of a SHM system [5]

A smart algorithm that can be used in SHM systems must take account of the main operation of the signal processing. In this process, it is necessary the conversion of the signals in features. After identifying the damage type and its source it is necessary to determine which technique should be applied in the damage assessment. The data from the operational and environmental sensors are used to develop a data – based models that predict the future system loading. The solution process, obtained after the final step, will be iterated, basing on the evaluation on the specific situation to improve the prediction model.

3. THE CURRENT AEROSPACE APPLICATION OF SHM SYSTEMS

The principle of structural health monitoring process is based on the ability of a specific system to monitor structures using embedded or attached nondestructive evaluation (NDE) sensors and to use the data to assess the health state of the structure. Over the last ten years researchers have made significant work in developing NDE sensors for SHM, and they have developed the hardware and software needed for analysis and showing of the SHM results.

In aerospace area, at global level, there are developed and investigated a set of SHM systems, based on different sensing methods.

In their work, Qing et al [4] proposed the use of PZT sensor network (Figure 3) for damage detection. A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them to an electrical charge. The researches were done in China at the Nanjing University and they used a damage detection method based on the Lamb wave theory combined with the classical signal processing method. This SHM system based on PZT sensor network was applied on a wing box composite structure to estimate the impact location and the delamination. Also, they used the Fiber Bragg Grating (FBG) sensors to monitor the temperature and the strain of aircraft structure.

Fig. 3 A PZT sensor layer [4]

Other researchers, Finlayson et al. [6] proposed the use of acoustic emission method for detecting the damage in the helicopter drivetrain.

Acoustic emission sensors are used to detect and monitor the ultrasonic waves that are produced by materials when materials undergo fractures that can lead to structure failure. Using the triangulation principle, an array of acoustic emission sensors attached to a structure can be used to determine the location of growing cracks in a structure. Moreover, some high sensitive fiber optic Bragg sensors, attached to the surface or embedded in a structure, can be used to detect acoustic emission signals. These signals are very weak and are necessary to be pre-amplified to eliminate the influence of the environment noises. This method can be easy applied for the composite structures. Due the ultrasonic waves generated by acoustic emission is rapidly attenuated, it is important to have an enough set of distributed sensors in composite structures.

They developed a complex SHM system based on AE sensors (presented in Figure 4) and this was tested on a fighter aircraft. Also, they used this SHM device in an experiment on the DC – XA – Delta clipper demonstrator. Related to their work, the researchers showed that the acoustic emission method has an important role in aerospace non - destructive testing on SHM systems.

Fig. 4 Acoustic emission sensor [6]

The ultrasonic methods [9] are, frequently used in the last 20 years, in aerospace application, to locate and identify the damage type. This method is based on the principle of the attenuation of the sound at high frequencies, when it crosses the structure material. In aircraft applications, this method supposes the existence of a performed scanning system for the investigation of the structure during its function. It is used an advanced technique with laser ultrasound where the scanning can be easy done by some lens (mirrors) which will change the direction of the laser wave. This principle is showed in Figure 5.

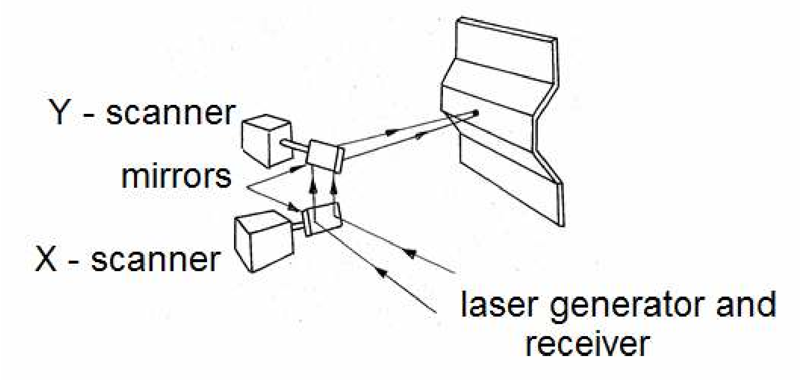

Fig. 5 The principle of the scanning with laser ultrasound [10]

Kosters and van Els [7] were done a series of researches in SHM systems in aerospace area. They used Fiber Bragg Grating sensors, placed in several locations on the aircraft components to measure the local deformation.
A fiber Bragg grating (FBG) [3] is a type of distributed Bragg reflector constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by creating a periodic variation in the refractive index of the fiber core, which generates a wavelength specific dielectric mirror. A fiber Bragg grating can therefore be used as an inline optical filter to block certain wavelengths, or as a wavelength-specific reflector.
In their work, they proposed a SHM system based on 4 sensors, a high speed de - multiplexer interrogation system, a data acquisition and processing system. The researchers used the SHM system on a CFRP composite aircraft structure. CFRP (carbon fiber reinforced plastic) materials are used in aerospace industry for primary aircraft structures, as fuselage sections.
Mielozyk et al. used in their researches [9] other sensing method for damage detection. They used the thermography method for to detect the delamination in a CFRP composite panel from AW 139 helicopter fuselage.
The thermography is a very used experimental method for damage detection that is located inside a structure material. It consists in the determination of the isothermal lines of the material surface. This method is based on the principle of visualization of the heat emission.
At the aircraft application, there are most used the electronic thermography method, with infrared detector. The principle of measure is relied on the thermoplastic effect which allows establishing a relation between the main stresses and the temperature. The resulted temperature distribution is detected, in real time, by the monitoring of the infrared radiation from the structure surface with a video – thermography camera.
A very quickly scanning can be realized using a system with mirrors that is rotated with very high speed. The infrared radiation emitted from the structure is reflected by the mirrors to the semiconductor material of the infrared detector. Once with the turning of the mirrors, a picture of the analyzed structure will appear on the monitor. This picture is called the thermal map.
They proposed and used an experimental set up consisted by an infrared camera SC 5600 FLIR, the halogen lamps and a PC computer. These halogen lamps were used to excite the face of the specimen during the testing. It was measured the delamination that occurred inside of the specimen material.

4. CONCLUSIONS

The developing of an optimum SHM systems is a current topic in aerospace industry in the entire world. At the global level, researchers are concerned to develop an intelligent embedded sensing system for damage detection and making a prognosis of the structure life. On an UAV the use of a SHM system may be more appropriate then the use of such system on a commercial or fighter aircraft.
The deployment of SHM system in the aircraft industry has a lot of benefits, especially the safety of the passengers.
For developing an ideal SHM system is necessary to implement a technology with smart sensors embedded in the aircraft structure. At current days, it does testing on different materials used in the aerospace industry, on

different components of the aircraft using different flight environment conditions (in peacetime or wartime operations).
At our days, many smart SHM systems are introduced in the aircraft technology but a complete structural health monitoring system is difficult for implementing due to the available level of the current technology.

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