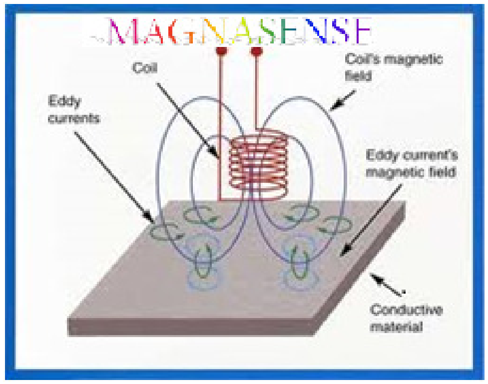


Magnetostrictive sensor applications for self-sensing of composite structures - MAGNASENSE

The aim of MAGNASENSE project was to develop the appropriate smart maintenance technologies, using magnetostrictive sensors, in order to enable self-sensing of the strain field developed in components manufactured by CFRP. For this reason, an innovative inductive technique based on the inverse magnetostrictive effect was introduced and special tracking/recording software to monitor the structural integrity of composite structures was developed. At the end of the project, a component scale demonstrator was manufactured (damaged stiffened panel repair with a bonded composite patch including embedded MsS), for the evaluation of the developed smart maintenance methodology. In order to succeed these goals, a five step development process was followed, comprising of:

a. Identification of appropriate strain sensitive magnetic wires (Magnetostrictive Sensor – MsS) to be applied to composite structures.
b. Development of a non-contact magnetic flux sensor arrays for quick scanning and strain mapping of the composite structures.
c. Numerical simulation of arrays of sensing elements, to correlate mechanical to magnetic readings.
d. Development of appropriate algorithms and software supporting the magnetic flux sensing.
e. Manufacturing of component scale demonstrator.

Within MAGNASENSE, a complete operational chain of prototype equipment, software and sensors was attempted to be produced, that enriches the technology fronts in structural health monitoring of CFRP structures. Self sensing of CFRP components is a major step towards improving reliability and performance of aircraft structural elements. The ability to reliably monitor developed strains during or after structural loading will greatly assist in reduction of aircraft weight, through lowering of safety factors, and minimization of aircraft downtime, by increasing inspection speed and enabling prompt isolation and quantification of damaged areas.

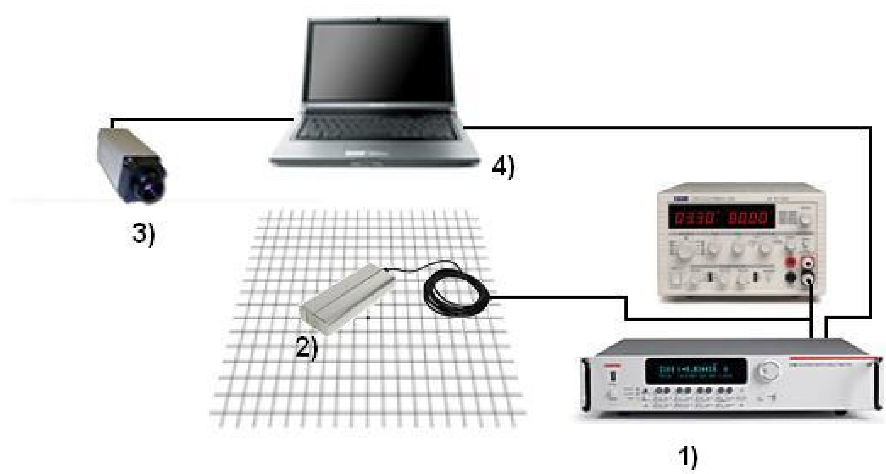
Within the MAGNASENSE project a special sensing system have been developed, in order to support strain sensing using MsS wires.

The sensing system, as presented in the following Figure, consists of:

a) An Infrared Camera.

b) A Transducer with an attached infrared led.
c) Voltmeter / Data acquisition system.
d) A Laptop running a special Sensing software.

All the required hardware and software that was developed for the application are combined in a prototype sensing system, whose operation is described below. The data acquisition system is connected to the inductive transducer and also to the computer through a LAN network, in order to measure and store the output data. The data acquisition system records the signal of the transducer converting the resulting samples into digital numeric values that can be manipulated by the computer. On top of the inductive transducer it has been attached an infrared led in order to be located by the infrared camera. The infrared camera is connected to the computer by a Bluetooth devise, in order to locate the position of the inductive transducer and provide the data to the sensing software. The camera can locate only infrared frequency. That ensures the isolation of the position signal of the transducer from external noise. The Laptop is running prototype sensing software (MagnasenseScanner) that was developed in Visual Studio 2008 environment using C++ programming language. The software uses proper libraries in order to communicate with MATLAB, data acquisition system and Bluetooth device of the camera.



MAGNASENSE Sensing System

The developed software combines the functionality of all hardware devices into a sophisticated sensing system. The innovative feature of this system consists on the technology of optical tracking. The recording of the sensors position occurs by a tracking camera that is placed firmly by the inspector, targeting the inspection area. The tracking camera scans the targeting area and detects the light that comes from the light emitter that is attached over the transducer. Using the developed software the sensing area is projected on a 2D screen coordinate, modeled and meshed into clusters. The inspection of each part (cluster) of the area is recorded transmitting X and Y position data. When the whole area is inspected, the operator can proceed with the 2D or 3D visualization of results, which indicate recorded transducers signal per inspected area, thus providing an overall mapping of the area.

The accuracy of the measurements is enhanced by appropriate filtering algorithms that were developed and incorporated in the software. Polynomial and spline fitting techniques are applied through software's data analysis to the multidimensional data. These mathematical techniques are appropriately adapted to smooth the data, taking into account the mechanism that generates them. Therefore, an extra median filter is being used taking into account the mutual relationship between neighboring measurements which sharing a common continuum.

Another important tool that has been developed and is included in sensing software package is the image correlation tool. This tool directly provides full-field "strain" signature by comparing the recorded images of the structure surface in the un-deformed (or reference) and deformed states respectively. In principle, this tool is an optical metrology based on digital image processing and numerical computing.
The project results were evaluated mainly based on the testing of the composite demonstrator, in order to assess its applicability and efficiency for aeronautical applications. According to those results, the Magnetostrictive strain sensing methodology developed within the MAGNASENSE project was able to measure strains within the repaired panel rapidly and in a non-contact manner, in order to indicate areas where potential damage existed. As repeatedly emphasized, the success of this technique is based on the comparison and correlation of current results with previous readings, taken from the same part at the same or other loading status. Through the comparison of those readings, the method can provide indications of internal damage, at very low cost, quickly, reliably and in a non-contact manner, regardless of the loading status of the component.

For the achievement of the above mentioned goals, there were **five (5) technical Work packages** in order to perform the research, development and testing activities of this project, together with two (2) additional Work packages supporting the technical activities, dealing with dissemination of results and project management. More specifically:

- Within **WP1** the methodology to be followed will be defined in detail. This will include the definition of basic project parameters and constraints, the typical geometrical and material cases to be covered by the methodology, the sensing requirements (strain sensitivity, spatial resolution etc.), etc. Moreover, candidate magnetostrictive materials in a wire form will be examined, in order to select the most appropriate for the extensive strain sensing of composite components, in terms of performance, cost, ability to be "knitted" in order to form a mesh etc. Additional properties of the metallic "mesh" will be examined, namely the lightning protection features, and specific materials will be selected in order to form the metallic mesh that will be able to simultaneous cover both the sensing and the LSP requirements.

- Within **WP2** the magnetic flux sensing elements will be developed and optimised. The sensor's configuration will include an outer coil which generates an altering magnetic field, according to the voltage incoming from a voltage generator, and an inner coil, which is a very sensitive voltage measuring equipment. As a next step, the arrangement of these magnetic flux elements will be performed in an array form, in order to enable quick covering of larger areas. In order to ensure the proper functionality of the array of sensors, the avoidance of EMI/EMC effects between adjacent sensors will be studied, through extensive modelling of magnetic flux sensors, while the appropriate software will be developed, to enable the simultaneous processing and visualization of several magnetic flux measurements.

- Within **WP3** the numerical simulation of characteristic damage cases will be performed, in order to identify the surface strain profile that they produce. Based on the FEA database produced within this Task, surface strain measurements will be then correlated to internal damage, thus enabling structural health monitoring of components, especially in the case of structural repairs, both for the cases of crack extensions when bonded composite repairs to metallic aircraft structures are applied and in the case of debonding / delaminations.

- Within **WP4** the appropriate sensing software and algorithms will be developed in order to support the magnetic flux scanning, convert magnetic flux to strain measurements, compare new to previous strain readings and correlate surface strain readings to internal damage, such as debondings, delaminations etc.

- Within **WP5** the manufacturing of the repair of a component scale demonstrator (damaged stiffened panel with stringers and frames, repaired by a bonded composite patch with embedded MsS) will be performed, for the evaluation of the developed smart maintenance methodology. A three-dimensional artificial damage, similar to the typical 2bay-crack damage (one stringer broken and the skin cracked on both sides of stringer - half-bay of skin on each side and the central stringer damaged), will be included. Finally, the results achieved within the project, mainly based on the testing of the composite demonstrator, will be considered, in order to evaluate the developed smart maintenance methodology against set criteria.

- **WP6**, will deal with the activities concerning dissemination and exploitation of research results produced within this project, attempting to maximize the knowledge transmitted from this research project to the scientific and the industrial world working on aeronautics. This Work package is considered of top importance, as the overall impact of the project and its effect to the European competitiveness largely depends on it.

- The Project Coordinator, GMI, will be mainly responsible for the implementation of **WP7**, which contains the project management and coordination activities as well as for the prompt periodical reporting towards EU and the "Topic Manager". Playing a key-role in the project, the Project Coordinator, is responsible for the adequate performance of the required management and coordination activities, as thoroughly described in Section 2 of this proposal.