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Wireless actuation of piezo-elements for the structural health monitoring of carbon-fiber-reinforced-polymers

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ABSTRACT

The goal of this research is to evaluate wireless actuation of Piezo-Wafer-Active-Sensors (PWAS) to generate Lamb-waves on Carbon-Fiber-Reinforced-Polymers (CFRP). Transmission is done by implementing inductive coupled coils. However, CFRP behaves as an electrical conductor, shielding radio waves with increasing worse effects at higher frequencies. Thus, there is a great interest to evaluate the kilohertz ranges. The actuator node is prepared by combining the PWAS bonded to the surface with an inductive coil and tuning all in resonance by adding passive components. In this way, the actuator receives a windowed-signal at the frequency provided by the coil system. An actuator node is prepared in order to evaluate the power transmission; while three sensors are used to measure the responses from the material. The measurements demonstrate that it is possible to wireless excite Lamb-waves. Finally, preliminary results show the feasibility to determine the presence of structural failure.

1. State-of-the-art

Structural Health Monitoring (SHM) consists of evaluating the status of a structure or its material. Generally, sensors and actuators are used to collect information about fatigue, material degradation, and negative environmental conditions. There is a growing interest towards wireless technologies that would enable SHM of carbon fiber reinforced polymers (CFRP) with applications in different industries, including but not limited to aeronautics, automotive and wind energy. CFRP structures are interesting because of their strength and light weight even though their complex mechanical and electrical anisotropic properties are a challenge for the integration of SHM systems. Embedded sensors in CFRP have been evaluated by [1,2] showing that the major challenge is the integration without affecting the low weight of the structure and without generating an impact to the material quality. Hence the interest in the use of small and very thin wireless powered systems. A method to evaluate structures in a non-destructive way is by implementing Lamb-waves. This guided ultrasonic plate waves propagate in a solid medium between two parallel surfaces over large areas; therefore, they are suitable for sparse sensor arrays. For SHM purposes, where the sensing ability is integrated in or onto the structure, Lamb-waves are most commonly excited and measured using piezoelectric elements.

By means of inductively coupled coils we eliminate the need for electrical connectors or wiring the piezoelectric elements. In consequence, it is possible to have a material integrated passive system, meaning no external source of power will be necessary. Moreover, the lifetime of such system will be longer than those active systems depending on a battery. The goal is to create a wireless sensor network to be used for structure monitoring by implementing inductively coupled coils together with piezoelectric elements. The principle is shown in Fig. 1. A mobile reader unit contains a transmitter coil to wireless actuate the piezo. The lamb-waves are detected by a piezo sensor and this voltage is directly read by an oscilloscope or it can be amplified and wireless transmitted back to the external unit. In the following sections the background principles are presented, both for Lamb-wave based SHM and for Wireless Power Transfer (WPT). In Sections 2 and 3 the limitations of the design will be explained including the frequency selection and the power transfer evaluation with the constrictions set by the selected piezoelectric elements. Furthermore, measurements with two different system approaches are explained. Each system has advantages and disadvantages that

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Nomenclature

Ψ	magnetic flux	N	number of windings
B	magnetic field	L	coil inductance
A	area of the coil	k	coupling factor between coils
μ_o, μ_r	permeability of free space and relative permeability	M	mutual inductance
D	coil diameter	C	capacitance
r	coil radius	z	distance between coils
h	height of the solenoid coil	S_{11}	antenna reflection coefficient
a	winding thickness for a planar coil	x	distance between PWAS-actuator and PWAS-sensor

are further discussed. Finally, some initial results in the damage detection are presented for an Actuator-Sensor system bonded to a CFRP plate. This paper is an extended version of the results presented in [3].

1.1. SHM based on Lamb-waves

Lamb-waves are a type of ultrasonic waves that remain guided between two parallel free surfaces, such as the upper and lower surface of a plate or shell [4]. More than one wave mode exist for each frequency. The modes at low frequencies are S_0, A_0 and SH, the latter one, denoting the shear horizontal wave. The symmetrical modes are called, $S_0, S_1, S_2, \ldots$ and the anti- symmetric ones $A_0, A_1, A_2, \ldots$ starting with the mode that has the lowest frequency for a given wave number [5]. These waves are easily excited and measured by integrated or surface-applied piezoelectric elements denoted as Piezo-Wafer-Active-Sensors (PWAS). They have successfully been used to identify and localize both discrete, localized damage, such as holes, notches, cracks, delamination or weak bonds [6] as well as distributed, non-localized damage such as fatigue in composites [7]. Examples for other investigations are characterization of the influence of moisture absorption on Lamb-wave propagation [8] or the inverse measurement of mechanical properties [9]. Especially interesting is the detection of non-visible and barely visible damages such as delamination, these are typical and hard to detect from outside the structure when using classical visual inspection methods.

Lamb-wave based SHM can be realized as a passive or an active system [10]. The first one uses the waves created by damaging events, such as crack initiation and growth or an impact event (hail, bird strike). In the active system an actuator is used to create the Lamb-waves in a controlled fashion. This work implements an active system and uses the pitch-catch-method. This method in comparison to the pulse-echo method does not use one piezo element for a measurement; instead it uses two, one as actuator and the other as sensor. Fig. 2 shows this principle of a SHM-System with piezoelectric elements bonded to the plates surface. An excitation signal is applied to a piezoelectric element (actuator). These generated waves depend on the interaction between actuator, adhesive and local material properties. While traveling dispersive through the structure, these waves are underlying damping due to viscoelastic material behavior and contact to surrounding fluids or materials. Reaching the sensor, the strains are transmitted through the bonding layer to the piezoelectric element, based on the inverse piezoelectric effect an electric output signal is created which then can be displayed and subsequently analyzed.

In an active SHM system a damage represents a discrete, local change of the waveguide which interacts with the propagating Lamb-wave. The signal analysis has to take into account that these waves are reflected at edges or transmitted through interfaces, and

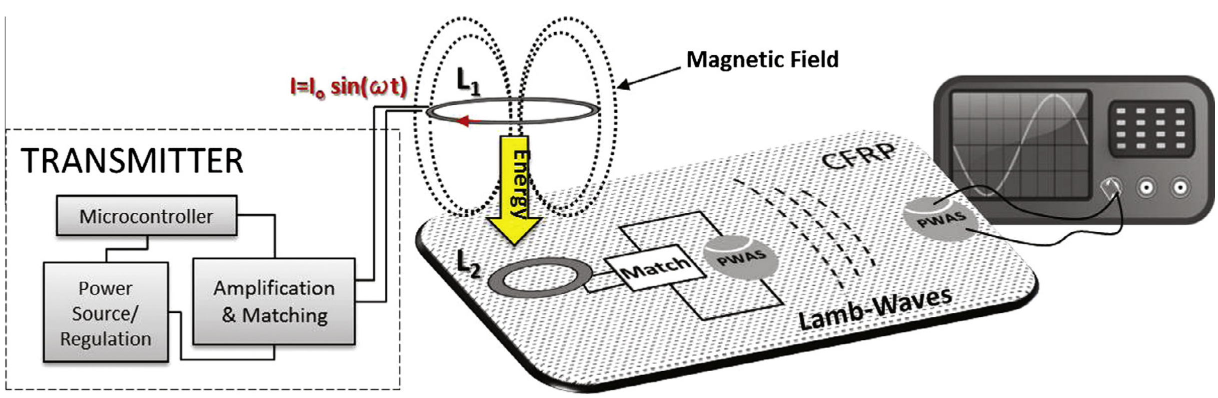

Fig. 1. Wireless SHM measurement system.

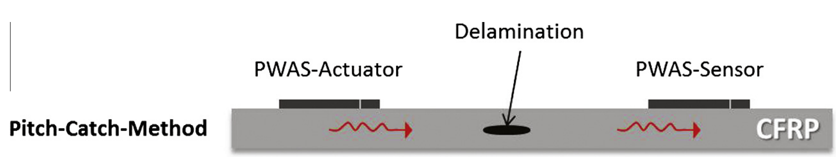

Fig. 2. SHM with piezo elements using pitch catch method [9].