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Potential Evaluation of Electro Mechano Gram (EMG) for Osteoporosis Detection

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ABSTRACT

Good health of bones is of the utmost importance to human beings. Smart materials like lead zirconate titanate (PZT) patches are small in size and carry less weight, which makes them most apt for biomedical structural health monitoring (BSHM). In the past, focus on the development of low-cost non-invasive techniques for real-time monitoring of critical bones has been undertaken as an alternative to current diagnosis techniques such as dual x-ray absorptiometry (DEXA), which is not portable and emits radiations. This paper presents a study to evaluate a previously developed non-bonded piezo sensor (NBPS)-based diagnostic technique for non-invasive detection of osteoporosis, in the framework of the electro-mechanical impedance (EMI) technique. As part of the study, the experimental trials in the paper are performed for comparing DEXA and bone electro-mechano gram (BEMG) on healthy subjects as well as those with osteoporosis. It was found that BEMG identified structural system for healthy and osteoporotic subjects were quite different leading to a new technique to identify osteoporosis.

KEYWORDS

Bone Electromechano Gram (BEMG), Dual X-Ray Absorptiometry (DEXA), Electro-Mechanical Impedance Technique (EMI), Osteoporosis, Structural Health Monitoring (SHM)

1. INTRODUCTION

Human health has always been a prime factor of concern with respect to self-development, societal needs or even the nation. In this regard, medical community have been investing tireless efforts to study, diagnose, enhance and improve human health by incorporating advanced technologies.

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Technologies used for diagnosing ailments in human bones like X-Ray, CT Scan, DEXA etc. are some of the techniques in this category.

DEXA or bone densitometry, is an improved version of x-ray technology for measuring bone mineral density. Till now, DEXA is the primary technique employed for detecting osteoporosis and has fulfilled its purpose to a reasonable extent. DEXA is generally available in major hospitals and prominent scan centres. Apart from its advantageous performance, some drawbacks like exposure of X-rays, high cost and underestimation of fracture due to small bone size and bone degeneration tend to limit its utility.

In this paper, an attempt has been made to evaluate piezo sensors as an alternative to DEXA for detection of mineral loss in bones, known in medical term as osteoporosis, based on electro-mechanical impedance (EMI) technique. This technique is currently employed for structural health monitoring (SHM) of civil and mechanical engineering structures (SHM) (Bhalla and Soh, 2003;Inman et al., 2001;Lim et al., 2006; Soh et al., 2000). In the bio-medical field, the enhanced approach is addressed as bone electro-mechano gram (BEMG) (Srivastava, 2018; Srivastava et al., 2017;Prakash, 2020). Advantages of the BEMG are: low-cost, easy handling, no fear of x-ray exposure to the humans and diagnosis of disease like osteoporosis. Potential evaluation with respect to DEXA and effective drive point impedance based parametric analysis for measuring the degree of osteoporosis need to be taken up.

2. METHODOLOGY

2.1 Electro-Mechanical Impedance Technique in Bio-Medical Engineering

Liang et al. (1994) invented the EMI technique. The dynamic response of the structure is measured using PZT patches in terms of admittance signatures. The PZT patches are held on to the structure via bonding using a high strength epoxy adhesive. The PZT patch performs the function of both sensor and actuator simultaneously. The fundamental principle behind this technique is that the structure is subjected to high frequency excitations (usually > 30 kHz) through the surface bonded PZT patches. Due to application of an alternating electric field, harmonic deformations are induced in the PZT patch which generates mechanical vibrations in the nearby structure. The structural response is then further transmitted from the patch as an electric signal, namely the admittance plots, consisting of the real component, conductance (G) and the imaginary component, the susceptance (B) as shown in Figure 1. Conductance and Susceptance, as functions of frequency, are the distinct unique signatures that convey information about the dynamic characteristics of structure. Any kind of structural damage changes these and especially the conductance, thus indicating damage. The imaginary part, susceptance is used for sensor and bond diagnostics. Variation in conductance signature of the patch recorded at any point of time as compared with the baseline measurement in the healthy condition points towards occurrence of damage.

Active and passive signatures are decomposed as per rule to extract the mechanical impedance of the host structure from the admittance signatures (see equation 1) of the surface bonded PZT patches (Bhalla and Soh, 2004). In equation 1, Z is the short-circuited 'effective mechanical impedance', Z_a the mechanical impedance of the PZT patch, $\overline{Y^E}$ the young's modulus of PZT patch at constant electric field, d_{31} the piezoelectric strain coefficient of PZT patch corresponding to axis '3' and '1', $\overline{\varepsilon_{33}^T}$ complex permittivity of PZT patch along axis '3' at constant stress, κ the wave number, υ the Poisson's ratio, h the thickness of the piezo patch, l the half length of the patch, w the thickness of the patch and ω the angular frequency. Based on the variation of the real part, x, and the imaginary part, y, of the impedance Z= x+yj, the host structure can be identified as a combination of basic elements namely spring, mass and damper (Srivastava et al., 2017; Bhalla et al., 2017). This is called as " impedance-based identification"