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Fatigue crack detection and identification by the elastic wave propagation method

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ABSTRACT

In this paper the elastic wave propagation phenomenon was used to detect the initiation of the fatigue damage in isotropic plate with a circular hole. The safety and reliability of structures mostly depend on the effectiveness of the monitoring methods. The Structural Health Monitoring (SHM) system based on the active pitch-catch measurement technique was proposed. The piezoelectric (PZT) elements was used as an actuators and sensors in the multipoint measuring system. The comparison of the intact and defected structures has been used by damage detection algorithm. One part of the SHM system has been responsible for detection of the fatigue crack initiation. The second part observed the evolution of the damage growth and assess the size of the defect. The numerical results of the wave propagation phenomenon has been used to present the effectiveness and accuracy of the proposed method. The preliminary experimental analysis has been carried out during the tension test of the aluminum plate with a circular hole to determine the efficiency of the measurement technique.

1. Introduction

In recent years the development of monitoring systems associated with the technological progress have been observed for example in aircraft or space structures. The necessity of permanent monitoring of the structures state and prognosis of the service life is especially important when the direct access for typical non-destructive testing methods is difficult or even impossible. Observation of the structures under fatigue loading is also significant from durability point of view. The great number of the engineering materials and difficulties associated with the accurate estimation of the fatigue strength cause the development of the Structural Health Monitoring (SHM) systems. In most cases the monitoring systems use pre-installed sensors and diagnose the structural health in real life. The Lamb wave propagation phenomenon is one of the most effective method for damage detection and identification in shell structures [1]. The basic assumption of SHM system is the comparison the potentially defected structure with the intact one to detect the change in the dynamic response [2]. SHM can be classified into several levels of analysis. The systems of the first level allow only to confirmation the presence of the damage. The main task of the second level systems is to determine the localization and orientation of the defect. The assessment of the damage size is the aim of the third level systems. The mentioned levels creates the diagnosis part of the SHM. The data from the diagnosis part can be utilized in determining the remaining life of the structures (the forth level) in prognosis part of the SHM [3]. The evolution of the fatigue damage starting from the edge of the hole in structure under

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different type of loading are considered by many researchers [4,5]. The guided wave propagation method is mostly considered in shell structures made of isotropic and composite materials [6–10]. The fatigue crack detection near the hole introduces the complications associated with elastic wave reflection from the boundary of the structure [11]. Many researchers are focused only on detection the damage near the hole by analysis of the wave scattering by crack [12,13]. The techniques of the damage identification are the subject of interest for researchers both in time and frequency domain [14,15]. A direct comparison of the signals from defected and intact structures has been utilized by Kessler [16], Giurgiutiu [17] and Stawiarski [18]. The localization of the fatigue damage by wave propagation method has been considered by Hong et al. [19]. The exemplary application of multipoint measuring system based on the PZT elements has been demonstrated by Wandowski et al. [20]. In this paper the wave propagation method has been used to detect, localize and assess the size of the fatigue crack in thin walled plate with circular hole. The SHM system consist of two part analysis. The first part is responsible for detection of the fatigue crack initiation. The second part observe and analyze the evolution of the damage growth and assess the size of the defect. The numerical analysis of the problem is implemented in ANSYS finite element analysis package. Preliminary experimental test verifying the wave propagation phenomenon during tension test has been carried out. The aluminum plate with a circular hole has been considered and the crack propagation has been observed and measured by elastic wave based system.

2. Configuration of the SHM system

The proposed multipoint measuring system based on PZT elements is responsible for the elastic wave generation and acquisition of the response data. The comparison of the intact and defected structure is necessary for proper damage detection and identification. In this paper the thin square plate made of PA38 aluminum alloy with circular hole in the middle is considered (Fig. 1).

The basic properties of the considered plate are presented in Table 1:

The configuration schema of the SHM system is presented on Fig. 2. The basic assumption of the considered case is that localization of the potential fatigue damage is predictable because of the assumed uniaxial fatigue loading applied in the horizontal direction. Many researchers proved that for such a case the fatigue crack starts from the edge of the hole and the orientation is perpendicular to the loading direction. The proposed SHM system is based on comparison of the signals received in the intact and defected structures. A presented measurement technique is called a pitch-catch method.

The hardware part of the system contain the multichannel elastic waves generation and acquisition system. In numerical FEM investigations the hardware part has been replaced by concentrated force (normal to the surface) applied to the plate in the compatible with the experiment form. The five cycle of the Hanning windowed (Eq. (1)) tone burst excitation signal was considered with the frequency f_0=250 kHz.

$$F(t) = \begin{cases} \frac{1}{2}F_0\left[1 - \cos\left(\frac{2\pi f_0 t}{n_0}\right)\right]\sin\left(2\pi f_0 t\right), & t \le \frac{n_0}{f_0} \\ 0, & t > \frac{n_0}{f_0} \end{cases} \tag{1}$$

where F_0=1000 [N] defines the amplitude of the applied force and n_0 is the number of counts in excitation signal. The form of excitation signal is shown in Fig. 3.

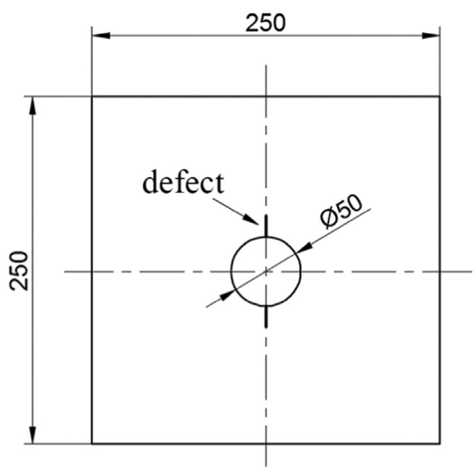

Fig. 1. Aluminum square plate with a circular hole in the middle.