754. Coherence analysis and transfer function model for ceramic plate vibrations

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Abstract. Correlations on the state of ceramic plates, that are either intact or cracked, are performed through the data obtained. In the analysis the frequency range of coherence has been identified in the form of the two regions. Low-frequency region is spectral amplitude that is below the threshold defined by the level of coherence about 0.2, which is on the level of little correlation. This region is in the frequency range of approximately 0-28 kHz. In this frequency range a weak correlation between the spectra of solid ceramic plates and cracked ones is observed.

Keywords: ceramic plate, cracked analysis, coherence analysis, transfer functions.

Introduction

Ceramic materials are now an integral part of our lives as a material in both the visual arts and industry [1, 2]. Ceramics and porcelain are one of the oldest materials that were used by humans [3]. Ceramic materials had an important place in our lives, especially as kitchen utensils, since the ancient times [1, 2]. These materials have many advantages such as high temperature endurance, lightweight (in comparison to metals), abundance of raw materials in nature and wear-resistance. Today, ceramic materials are used in computers, electronics and aerospace research [1-8].

The most important disadvantage of ceramic materials is their brittleness resulting from baking process. Since ceramic materials are composed of metal oxides, silicates, carbides, nitrides, borides, glass, etc. their crystal structures are very complex. The properties of ceramic materials are related to their bonding structure. In general, they have hard and brittle structure with low toughness. They isolate electricity and heat well. Due to their chemical atomic bonding structure they are stable chemically and have high melting temperatures.

The abundance of raw materials in nature, easy machining, the simplicity of fabrication, low cost of production, ease of use and practicality, hardness and heat resistance of ceramic materials enable their usage to increase. However, the most important problem encountered in ceramic materials, is that the material is brittle and can be deformed easily. The biggest drawback of ceramics and porcelain being used as kitchenware in the industry is its cracking and deformation feature. Due to the structural properties, surface cracks, voids, ruins form. The cracks and fractures form because of coarse grains appearing in the production process [1, 7].

The observed tensile strength is about 0.70 MPa. Some of the ceramics produced in private, with Al2O3 fibers, 7000 MPa can be reached. The impact resistance of hard ceramic materials is low because of their ionic covalent bonds [1, 6-8].

Stacking, storage errors of some ceramics can cause various deformations. Fractured surfaces or cracks may occur as a result of storage and truck negligence [1, 7]. Since the detection of cracks can not be distinguished through naked eye, some special methods are needed in order to determine these deformations. In this study, the cracks formed on ceramic plates are detected through impact noise method and are examined by statistical methods.

2. Coherence

2. 1. Power Spectral Density and Coherence Approach

A common approach for extracting the information about the frequency features of a random signal is to transform the signal to the frequency domain by computing the discrete Fourier transform. For a block of data of length *N* samples the transform at frequency $m\Delta f$ is given by:

$$X(m\Delta f) = \sum_{k=0}^{N-1} x(k\Delta t)\exp\left[-j2\pi km/N\right], \tag{1}$$

where Δf is the frequency resolution and Δt is the data-sampling interval. The auto-power spectral density (APSD) of $x(t)$ is estimated as:

$$S_{xx}(f) = \frac{1}{N}\left|X(m\Delta f)\right|^2, \; f = m\Delta f. \tag{2}$$

The cross power spectral density (CPSD) between $x(t)$ and $y(t)$ is similarly estimated. The statistical accuracy of the estimate in Equation (2) increases as the number of data points or the number of blocks of data increases.

The cause and effect relationship between two signals or the commonality between them is generally estimated using the coherence function. The coherence function is given by:

$$C_{xy}(f) = \frac{\left|S_{xy}(f)\right|}{\sqrt{S_{xx}(f)S_{yy}(f)}}, \; 0 < C_{xy} < 1, \tag{3}$$

where S_{xx} and S_{yy} are the APSDs of $x(t)$ and $y(t)$, respectively, and S_{xy} is the CPSD between $x(t)$ and $y(t)$. A value of coherence close to unity indicates highly linear and close relationship between the two signals [13-15].

3. Measurement System and Data Collection

Pendulum is used in this study in order to produce constant impact. Impact pendulum is a developed pendulum model that is used to produce pulses of equal size [1, 12].

Striking with the equal-sized pulses which will not damage the ceramic plate are provided through a small plastic hammer that is fixed on the tip of the impact pendulum, and the sound from the plate is subjected to the analysis [1].

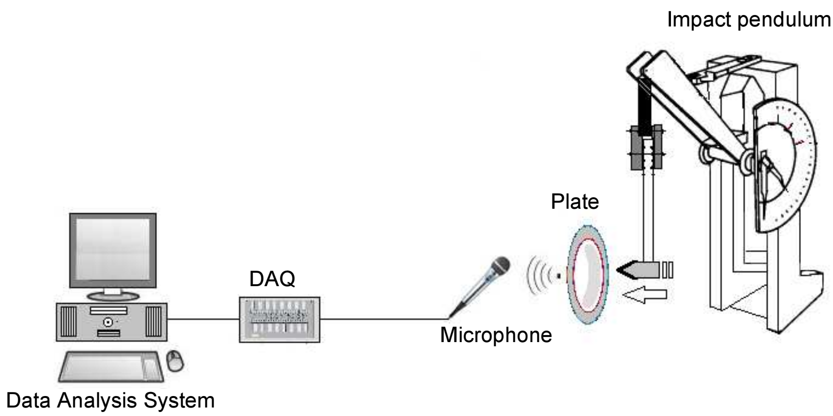

Fig. 1. Data acquisition and measurement system [1]

In this study, by using POE 2000 Pendulum Impact the effect that will make the same intensity pulse would hit ceramic plate has been provided. Here by means of Pendulum Impact, the sound generated from the implementation of the impact to the plates that have some cracks or not is transmitted to the data collection system through a microphone and then it is transmitted to the computer, where data processing phase is executed [1].

The output audio data of the amplifier is transmitted to the computer at a sampling rate of 0.00001 seconds via Advantech 1716L Multifunction PCI card and data analysis is performed using Matlab (Fig. 1).

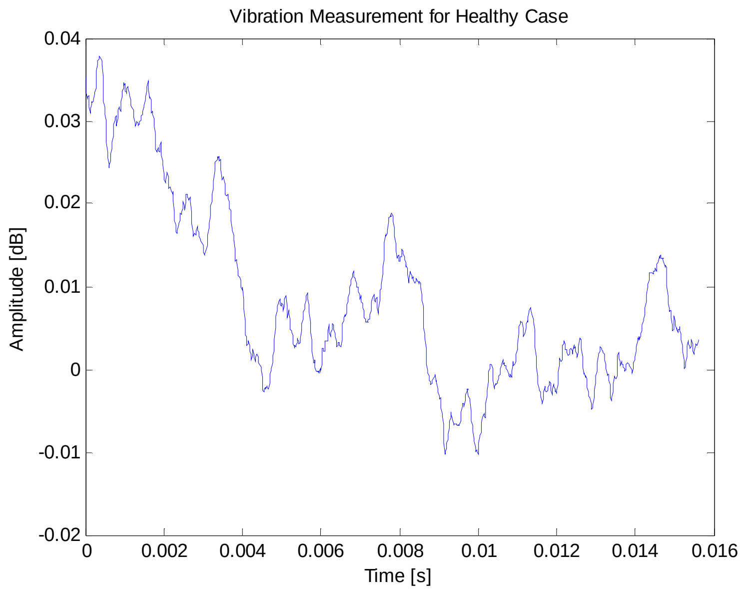

Fig. 2. Vibration measurement for healthy case

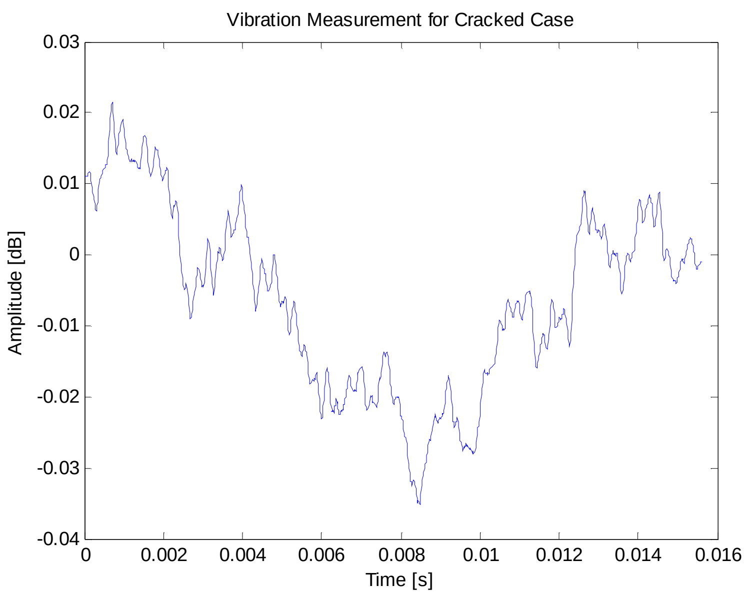

Fig. 3. Vibration measurement for the cracked case

Coherence frequency range can be divided into two regions. Low-frequency region is the spectral amplitudes at little correlation levels, below the threshold defined by about 0.2 coherence level. This region corresponds to the range of approximately 0-28 kHz. In this frequency range, a weak correlation between the spectra of solid and cracked ceramic plates is observed. Because the ingestion of sound waves by homogenous and non-homogenous ceramic material is different and this region reflects the properties of more defective plates.

In terms of mathematical comments a low level of correlation in this region indicates the diversity in the structural properties of two materials. On the contrary, the high-frequency region of 28-33 kHz shows the structural properties homogeneous regions of the solid and the crack plates, i.e. in both cases as a measure of similarity in the situation when there is no crack it indicates a high correlation of level amplitudes.

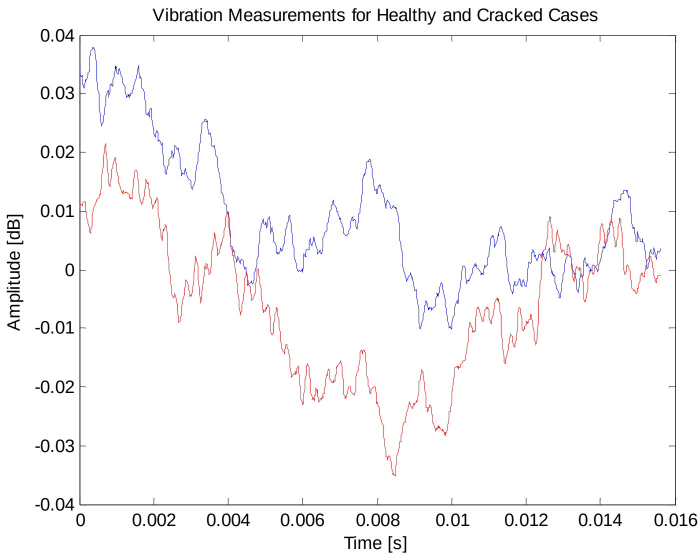

Fig. 4. Vibration measurements for the healthy and cracked cases

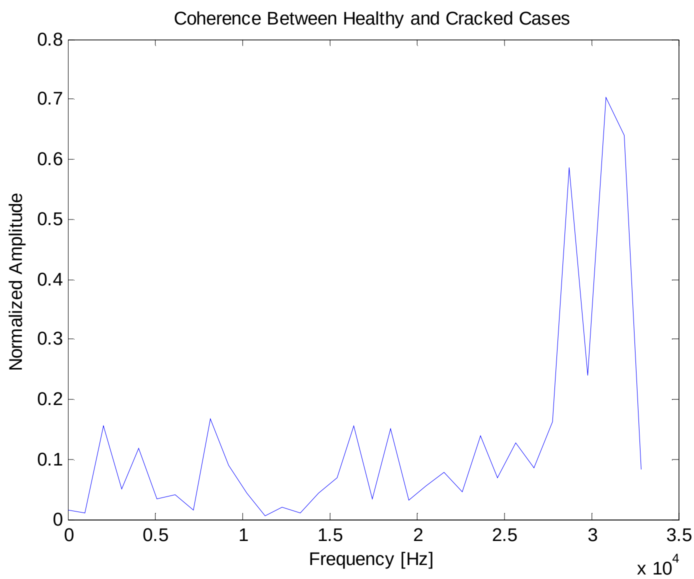

Fig. 5. Coherence between the healthy and cracked cases

As shown in Fig. 5 the level of correlation in this frequency range is about 70%. In this sense, correlation analysis clearly reveals in which frequency range the defective plates will give a response to sound waves. Here, the problem can be regarded as a reverse problem and two different states of material can be determined through low correlation or uncorrelated states.

Besides the correlation analysis in Fig. 5, similar relations can be observed by following the changes in Fig. 6 using the transfer function approach between intact and crack situation. In this case while a decrease in amplitude spectrum of transfer function up to 28 kHz is being observed after this value an increment that would reach a peak point around 30 kHz is observed. This shows the bandwidth of transfer function between the status of cracked and intact plate can be taken as 0-28 kHz as it is in the correlation relationship.

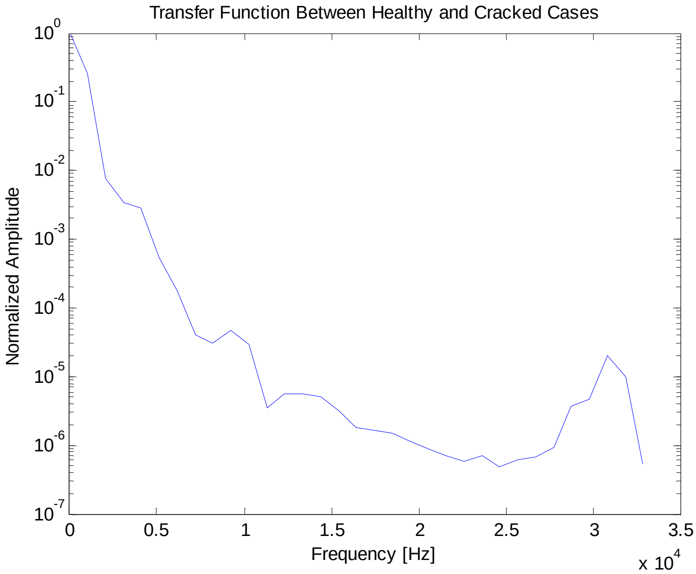

Fig. 6. Transfer function between healthy and cracked cases

4. Conclusions

In this study, in order to analyze cracks and solid states of ceramic plates an experimental system was set up and the data was obtained. Correlation analysis in relation to states of ceramic plates (being cracked or solid) was performed by using the collected data. In addition, a transfer function approach was obtained according to the state of ceramic plates being intact and cracked from analysis. It was observed that this approach was consistent with the results obtained from the observed correlation. Differences and similarities between the cracks in a solid analysis of the plates were revealed. Features obtained from the correlation of sound and cracked plates were found to be around 0-28 kHz.

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