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DETEKCE TRHLIN V BETONU METODAMI NELINEÁRNÍ AKUSTICKÉ SPEKTROSKOPIE
DETECTION OF CRACKS IN CONCRETE USING NONLINEAR ACOUSTIC SPECTROSCOPY METHODS

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Abstrakt
Na základě studia nelineárních akustických efektů byly navrženy nové defektoskopické a diagnostické metody. Tyto metody využívají faktu, že trhlinou vyvolaná nelinearita je citlivý indikátor poškození materiálu. Analýza nelineárních efektů byla provedena pro nepoškozené betonové vzorky i vzorky vystavené zmrazovacím cyklům. Výsledky naznačují, že metody nelineární akustické spektroskopie jsou velmi citlivé techniky pro detekci trhlin vyvolaných zmrazovacími cykly.

Klíčová slova: *nelineární akustická spektroskopie, zmrazovací cykly, beton*

Abstract
On the basis of nonlinear acoustic effect research, new diagnostic and defectoscopic methods have been designed. These methods are using the fact that a crack-induced nonlinearity makes a sensitive material impairment indicator. The nonlinear effect analysis was carried out for both intact concrete specimens and specimens, which had been exposed to freeze-thaw cycles. Results suggest that the nonlinear acoustic methods are very sensitive techniques for crack detection caused by freeze-thaw cycles.

Key words: *nonlinear acoustic spectroscopy, freeze-thaw cycles, concrete*

1. Introduction

On the basis of non-linear effect studies, new NDT methods have been designed [1, 2, 3]. These methods are based on the elastic wave non-linear spectroscopy. Existing linear acoustic methods focus on the energy of waves reflected at structural defects, analyzing the reflected wave energy, wave velocity or amplitude variations. However, none of these "linear" wave characteristics is as sensitive to the small cracks as the specimen non-linear response [4, 5, 8]. In this way, non-linear methods thus open new horizons in non-destructive acoustic testing, providing undreamed-of sensitivities, application speeds and easy interpretation. One of the fields in which a wide application range of non-linear acoustic spectroscopy methods can be expected is civil engineering, for example for fatigue damage assessment [4, 21], micro-damage diagnostics [5,6], or monitoring of the early hydration process in concrete [7, 22]. It is predicted that these advanced techniques can contribute a great deal to the improvement and refinement of the NDT methods in the building industry practice. [16, 17, 18]

2. Non-Linear Spectroscopic Methods

We classify non-linear acoustic spectroscopy methods to resonant and non-resonant [9, 11]. Non-resonance methods are used to study suppressed resonance specimens. These methods analyze the effect of nonlinearities on acoustic signals propagating through them. These methods can again be split into two groups [9]: measurements using a single harmonic ultrasonic signal (single exciting frequency f_1) and measurements using multiple harmonic ultrasonic signals - mostly two exciting frequencies f_1, f_2. There is also possibility to combine one ultrasonic and one electrical signal with different frequencies [10, 19, 20].

We pay attention to single harmonic ultrasonic signal measurement method which was used in experimental part. In this case, where a single exciting frequency f_1 is used, the non-linearity gives rise to other harmonic signals, whose frequencies f_v obey the Fourier series formulas:

$$f_v = n \cdot f_1 \qquad \text{where } n = 0, 1, 2, \ldots\infty \tag{1}$$

Amplitudes of f_v are falling when the n is increasing. If the nonlinearity effect is not entirely symmetrical, amplitudes of even-numbered harmonic components may be much lower than those of the odd-numbered ones. Among these emerging components, the third harmonic is the most distinctive one and its amplitude is being analyzed most often.

3. Measuring Apparatus

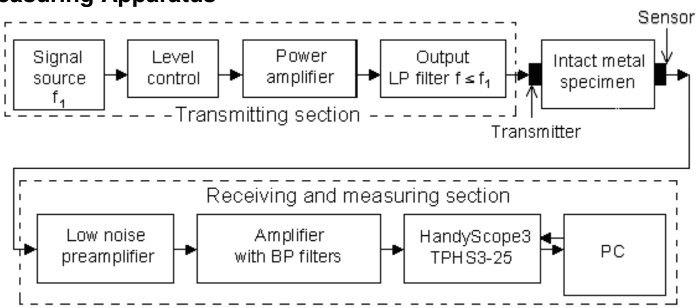

Fig. 1: Block diagram of the measuring apparatus

The transmitting section consists of four functional blocks: a controlled-output-level harmonic signal generator, a low-distortion 100 W power amplifier, an output low-pass filter to suppress higher harmonic components and ensure high purity of the exciting harmonic signal and a piezoceramic transmitter (actuator) to ensure the ultrasonic excitation.

Receiving section consists of piezoceramics sensor, low noise preamplifier with classical or differential input connector, amplifier with band - pass filters and spectral analyzer. In our case spectral analyzer was oscilloscope HandyScope3 TPHS3-25 controlled by computer.

4. Experiment

Firstly, we studied the concrete specimen structure having been stressed by thermal shocks. Testing specimens were concrete cubes, proportions 150 × 150 × 150 mm. The concrete specimens were stressed by recurrent freeze-thaw cycles. Measurements were realized before and after 30 and 60 freeze-thaw cycles.

The curve shown in figure 2 shows the BV001 specimen's pre-degradation frequency spectrum. Its shape features a gradual amplitude drop, without any non-linear effects. The transfer characteristic, figure 3, which corresponds to the same specimen having been subjected to 60 freeze-thaw cycles, does show a non-linearity. They consist in a drop of the second harmonic's amplitude and an increase of the third harmonic (3H). Figure 4 shows the high harmonics' amplitudes relative to the first harmonic's amplitude for all nine specimens together (specimens BV001 – BV009). We can see relative increasing of third and decreasing of second harmonic amplitude depending on number of freeze-thaw cycles. It is evident mainly after 60 cycles.

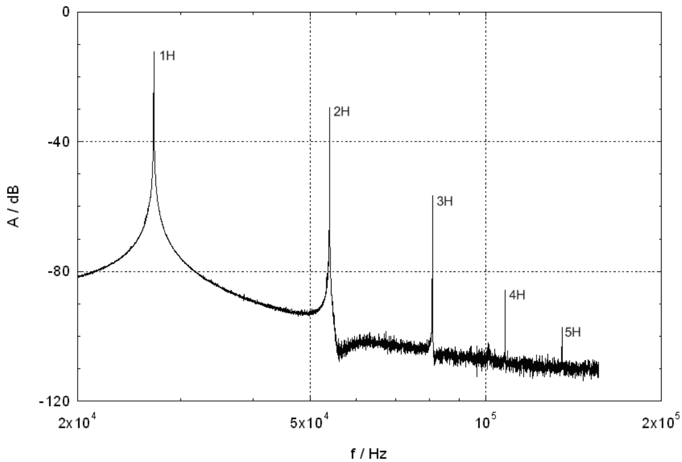

Fig. 2: Specimen BV001 before degradation – 0 freeze-thaw cycles

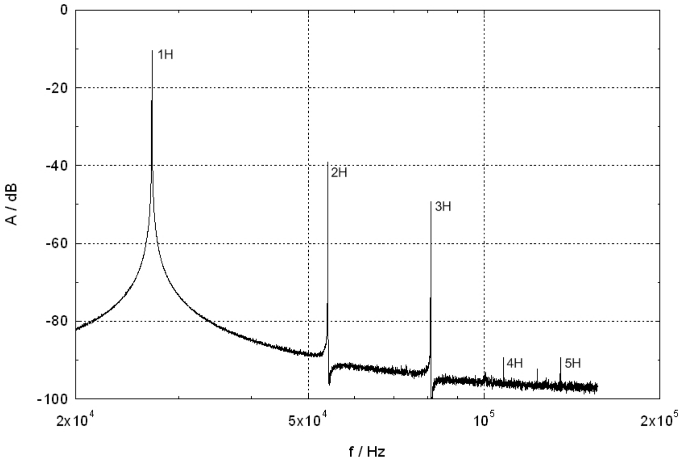

Fig. 3: Specimen BV001 after 60 freeze-thaw cycles

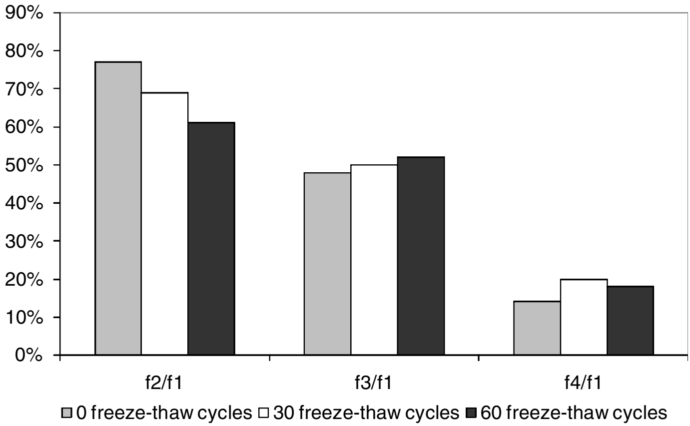

Fig. 4: High harmonics' amplitudes relative to the first harmonic's amplitude for all nine specimens

Secondly, we studied the impact of air-entrainment of concrete on results obtained by non-linear acoustic spectroscopy method with one exciting signal. Freeze-thaw durability of concrete has close relationship with its pore structure. The volume, radius, and size distribution of pores decide the freezing point of pore solution and the amount of ice formed in pores [15].

Testing specimens were concrete cubes too, same proportions as before. First group of specimens was made from the air-entrainment concrete. Second group was made from the same concrete but without air-entraining admixture. On figure 5 is a frequency spectrum obtained by single harmonic ultrasonic signal method. The specimen was made from the air-entrainment concrete.

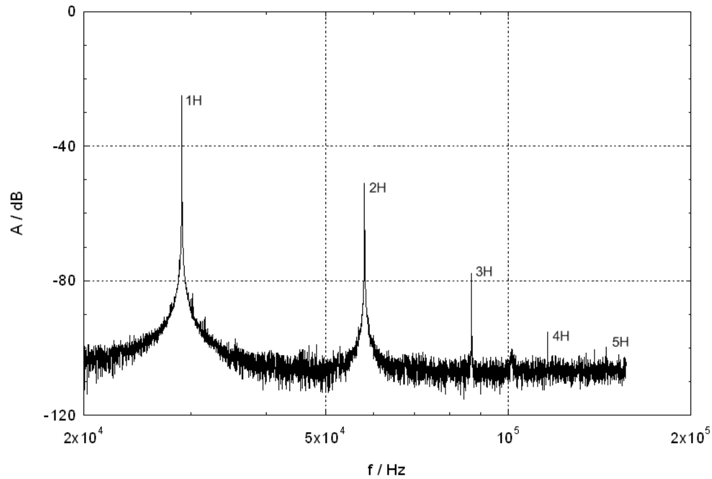

Fig. 5: Frequency spectrum – concrete specimen with air-entraining admixture

On figure 6 is frequency spectrum for the specimen which was made from the concrete without air-entraining admixture. There is no distinct non-linearity on both frequency spectrums. We can see only higher attenuation of the air-entrainment specimen.

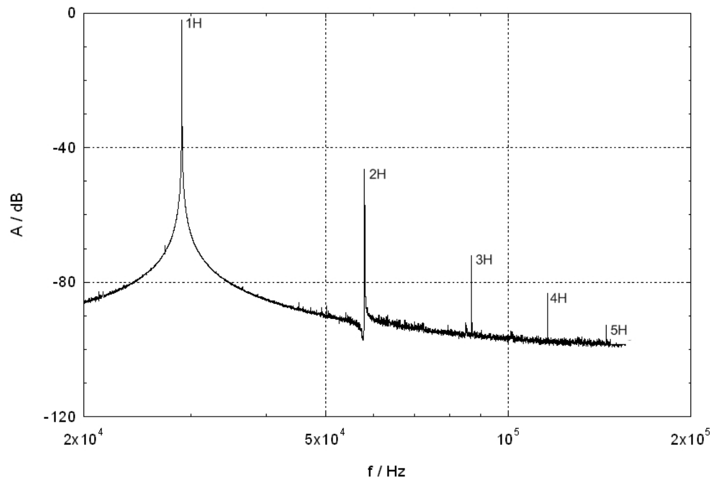

Fig. 6: Frequency spectrum – concrete specimen without air-entraining admixture

Figure 7 shows the high harmonics' amplitudes relative to the first harmonic's amplitude for all twelve specimens together. Again, there is no distinct non-linearity and we can see only higher attenuation of the air-entrainment specimens.

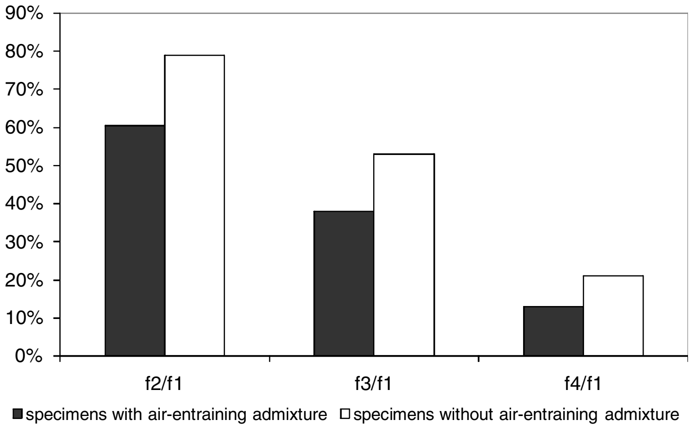

Fig. 7: High harmonics' amplitudes relative to the first harmonic's amplitude – all specimens – concrete with and without air-entraining admixture

5. Conclusion

This paper presents our results of concrete specimen structure testing by means of non-linear acoustic spectroscopy using a single exciting harmonic frequency method. Frequency spectra of freeze-thaw cycles loaded specimens showed non-linear effects to be present. Especially amplitude of third harmonic component looks like very sensitive indicator of damage caused by freeze-thaw cycles. Air-entrainment of a concrete caused only a higher attenuation of the exciting signal.

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