Česká společnost pro nedestruktivní zkoušení materiálu
37. mezinárodní konference **DEFEKTOSKOPIE 2007**
Praha, 7. - 9. 11. 2007

NONLINEAR ULTRASONIC SPECTROSCOPY OF CERAMIC SPECIMENS

Marta KORENSKA*, Michal MATYSIK*, Monika MANYCHOVA**

*Department of Physics, **Department of Building Structures,
Faculty of Civil Engineering, Brno University of Technology

ABSTRACT

The non-linear ultrasonic spectroscopy brings new prospects into the acoustic non-destructive testing of material degradation. On the basis of non-linear effect studies, new diagnostic and defectoscopic methods have been designed, which are based on the elastic wave non-linear spectroscopy. The linear acoustic methods being in use until now focus on the energy of waves reflected at structural defects, from reflected wave energy, wave velocity or amplitude variations. However, that none of these linear wave characteristics is as sensitive to the structural defect occurrence as the non-linear response of the material. Non-linear methods thus open new horizons in non-destructive acoustic-method-based testing, providing undreamed-of sensitivities, application speeds and easy interpretation.

One may state that, on the one hand, and, regarding the topic complexity, the requirements for newly developed special instrumentation and a high potential application diversity, the research and development of the respective methods, the required instrumentation and, last but not least, practical applications of these methods, is still in its infancy. On the other hand, most published papers as well as our experience show these methods to be highly promising for both the defectoscopy and the material testing purposes in the near future.

One of the fields in which a wide application range of non-linear ultrasonic spectroscopy methods may be expected is civil engineering. Poor material homogeneity and, in some cases, shape complexity of some units used in the building industry, are heavily restricting the applicability of "classical" ultrasonic methods.

The present paper deals with analyzing one of the non-linear ultrasonic defectoscopic methods from the viewpoint of its application to the ceramic specimen structural integrity evaluation.

Keywords: ultrasonic defectoscopic methods, inhomogeneous materials, material degradation, ceramic specimens, structural integrity

1 INTRODUCTION

The non-linear behaviour measurements are likely to be one of the most sensitive and affordable methods for study and early detection of defects. The dissemination of these methods' application may be expected to bring enormous economic and safety impacts. Although the topic as such is of rather basic research nature, we expect the new defectoscopic methods to be introduced in the practice and the existing methods to increase their yield and reliability in this building industry branch promptly and on a large scale.

Taking advantage of the mentioned benefits, the ultrasonic defectoscopy makes it possible to carry out the following:

- Fast one-shot (integral) testing of entire bodies (including bodies of complicated shape), which could be well applicable to the mass production of small and medium-sized elements (roof tiles, ceramic ceiling slabs, etc.)
- Increase in accuracy and sensitivity of defect localization methods, where the application of classical ultrasonic methods is restricted, to a high degree, due to the material inhomogeneities
- Defectoscopy-based constructed facility condition assessment and life estimate (for example, for bridge structures, hourdis slab ceilings, etc).

2 EXPERIMENT

Application of highly inhomogeneous materials featuring suppressed resonance effects in most cases is typical of the current material research in civil engineering. To study such materials, non-resonance methods are more suitable. These methods analyse the effects of non-linearity's on acoustic signals propagating through them.

2.1 Ceramic Tiles

The group of ceramic tile specimens, of dimensions 33 cm × 33 cm × 0,9 cm, their bending strength values having been determined to ČSN EN ISO 10545-4, were divided into three subgroups:

- The first subgroup – non-frozen specimen of Nos 310, 311, 312
- The second subgroup – the specimens which had undergone 300 freeze-thaw cycles
- The third subgroup – accelerated degradation (liquid nitrogen vapour cooling (about - 70°C)), specimens No. 401N, 402N, 403N.

The frost resistance determination method followed that described in ČSN EN ISO 10545-12 standard. Having been saturated with water, the specimen were exposed to alternating temperatures stress, namely, +5°C and -5°C. The specimen are intended to be subject to a many-sided freeze and thaw stress treatment a total of 300 cycles.

The accelerated degradation test was carried out by putting the soaked tiles into a cooling box to be kept at a temperature of -70°C for 10 minutes. Nitrogen vapours wee used to produce the low temperature. The tiles were subsequently dried in a dryer at a temperature of 110°C. A total of four degradation test cycles have been applied.

These measurements aimed at verifying whether the inhomogeneous structure of the specimens material under investigation makes a source of non-linear phenomena

in the signal propagation and, if so, to find out the variations in the frequency spectra correlating with the specimen degradation induced structural defects.
The experiment setup is illustrated by a photo shown in Fig. 1.

Fig. 1 Photo of experiment setup

2.1.1 Measurement Results

The first measurement of the exciter-specimen-sensor assembly was carried out on the intact specimen group. The exciting frequency was 29 kHz. The results of these measurements are represented by those obtained from tile No. 312. Fig. 2 shows the response frequency spectrum. A drop in higher-harmonic amplitudes with increasing harmonic serial number is evident. No non-linear effects are apparent.

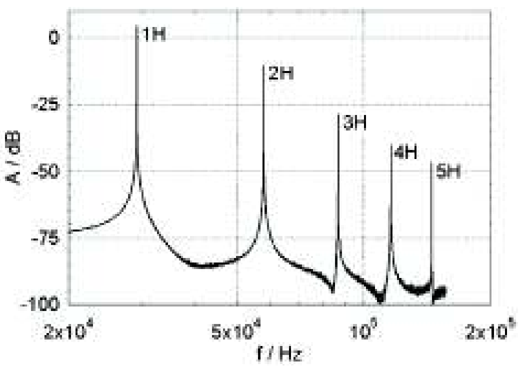


Fig. 2. Frequency spectrum of tile no. 312 (intact)

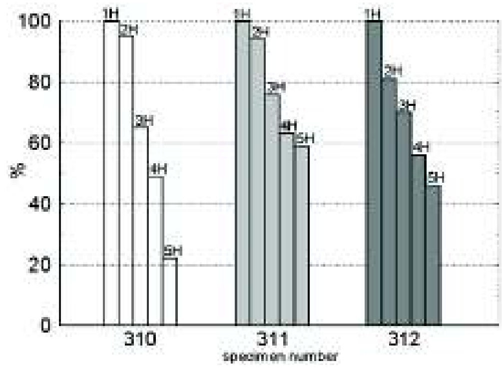


Fig. 3 Relative values of amplitudes

Let us designate the relative first-harmonic amplitude 1H (see Fig. 2). The second harmonic amplitude of specimen No. 312 then will reach 2H 95%, the third harmonic's 3H 65%, the fourth harmonic's 4H 50% and that of the fifth harmonic 5H 22%. Relative harmonic amplitudes – for the three intact specimens – are shown in Fig. 3. Our measurement results obtained from intact tile specimen, Fig. 3., show that no non-linear effects in the signal propagations are due to the inhomogeneity of the ceramic material. A drop of the harmonic frequency amplitudes with increasing harmonic serial number is apparent in the picked-up response frequency spectra.

Measurement results obtained from the second subgroup, where the tiles were degraded in three hundred freeze-and-thaw cycles, are represented by specimen No. 410 in Fig. 4.

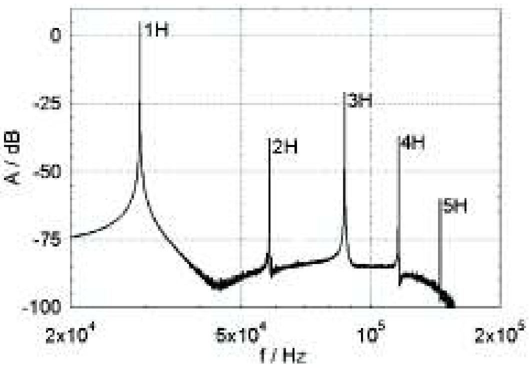


Fig. 4 Frequency spectrum of tile No 410 (after 300 freeze-thaw cycles)

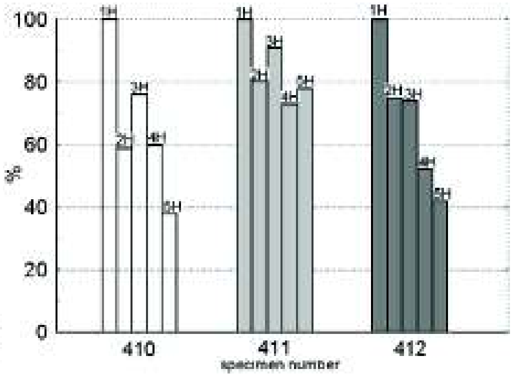
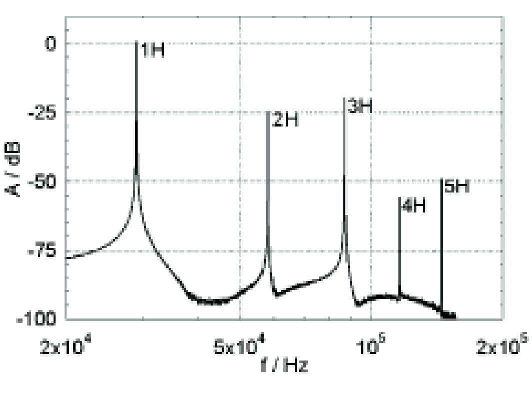


Fig. 5 Relative values of amplitudes

In this specimen’s frequency spectrum, the third harmonic’s amplitude exceeds that of the 2nd harmonic, which is comparable with the 4th harmonic’s one. Starting from the third harmonic, the higher harmonics keep decreasing steadily. Fig. 5 compares the relative amplitude values for the three degraded specimens. If the specimen were subjected to thermal stress of both modes, the material structure defects influenced the transfer functions in such a way that the progressive amplitude drop does not follow the harmonic serial number growth. The frequency spectra of the specimens stressed by 300 hundred freeze-and-and cycles. Fig. 5 show that the 3rd harmonic amplitude 3H is emphasized. Its value is higher than or – in the case of specimen No. 412 – comparable with the 2nd harmonic amplitude 2H.

The measurement results obtained from the third subgroup, where the specimens were immersed in liquid nitrogen vapours (about -70^{o}C), are represented by specimen No. 403N, Fig. 6.



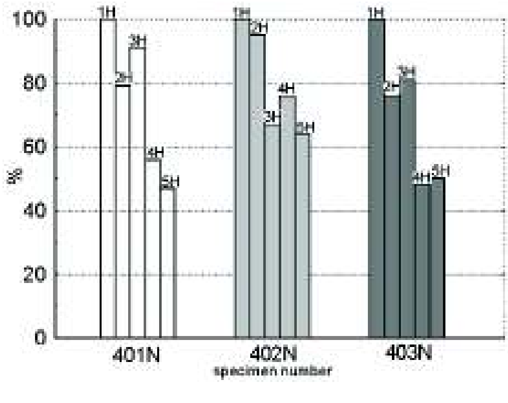


Fig. 6 Frequency spectrum of tile No. 403N (after degradation -70^o C)

Fig. 7 Relative values of amplitudes

The frequency spectrum corresponding to this specimen is shown in Fig. 6. In this diagram, the second predominating frequency is again that of the 3rs harmonic 3H, but, in contrast to the spectrum shown in Fig.. 4, the 5th harmonic exceeds in amplitude the fourth harmonic 4H.

Fig. 7 compares the relative amplitudes of the higher harmonics for all of the three specimen of this subgroup. The frequency spectra of liquid nitrogen vapour (-70°C) degraded specimens show non-linearity signs. The transfer functions of specimen No. 401N and 403N emphasize again the third harmonic 3H, partially emphasizing the 5th harmonic 5H in specimen No.403N. In specimen No. 402N's frequency spectrum, the fourth harmonic 4H does not fit to the harmonic amplitude decreasing trend.

3 CONCLUSION

Our measurements show that the effect of a material inhomogeneity is very low in the case of non-linear ultrasonic spectroscopy, its non-linear effect being substantially lower than in common defects. It has also been verified that the transfer functions of degraded specimen correlate fairly with the material structure defects.

Acknowledgements

This research was supported by the Grant Agency of the Czech Republic under Grant 103/06/P401 and as part of the research project MSM 0021630519.

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