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Structural health monitoring during white-noise vibration testing using total harmonic distortion

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1. Introduction

Pursuing idle time and cost reduction in production plants, structural health monitoring (SHM), making possible to predict machines failures and thus providing possibility to improve maintenance planning, could be advantageous. In beginnings of development of SHM methods classical approaches using spectral analysis were mostly used. Basic methods are described e.g. in [1, 3]. Today, with large development of sensors and data acquisition SHM methods based on deep learning, artificial neural networks and other means for Big Data evaluation are on the rise. Review on deep learning methods is provided e.g. in [5].

In vibration testing sweep sine or white-noise excitation are commonly used. Novel ideas for structure's health evaluation during white noise excitation could be found in [2].

Total harmonic distortion (THD) expresses rate of harmonic components in output signal. THD is more often mentioned in connection with sound or electric signals, but its usage could be extended. In this article we present a method, which uses white-noise excitation during vibration testing and computation of THD to evaluate state of the testing assembly. As far as we know, THD is used for structural health evaluation solely while using sine sweep excitation like in [4]. Our goal is to continuously evaluate the state of the testing assembly to detect any kind of damage (loosened screws, hidden cracks, etc.), which may devaluate ongoing vibration test.

2. Total harmonic distortion

Proposed algorithm is based on computation of THD, which determines the ratio between fundamental frequency of excitation and its harmonic frequencies. Harmonic frequencies are the integer multiples of base frequency. THD is commonly calculated as

$$THD = \frac{\sqrt{A_2^2 + A_3^2 + A_4^2 + \cdots + A_n^2}}{A_1} * 100 \quad [\%],$$

where A_n is the amplitude of n-th harmonic frequency. A_1 is base frequency of excitation. In case, where excitation is in form of white-noise all frequencies in predefined interval are present in input signal, if measured window is long enough. This means that within the range of excitation each frequency could be considered as fundamental frequency as well as harmonic frequency of several previous fundamental frequencies and thus the amplitude consist of base excitation and harmonic components.

3. Algorithm

Before beginning of measurement several parameters are chosen or computed: frequency vector, which defines frequencies in which THD is computed, number of harmonic frequencies included in THD calculation, excitation limit frequency which is the maximum frequency present in white noise excitation, batch length of input accelerometer signal *L*, length of multiplying window *W* and number of overlapping samples *M* of two consecutive signal batches. Except the limit frequency, all parameters are subject of optimization. For better FFT performance parameters *L*, *W*, *M* are recommended to be chosen in form of m^2, where *m* is a positive integer.

Input signal from chosen accelerometer is processed in batches of length *L*. Each batch is multiplied by Blackman window and fast Fourier transformation (FFT) is performed to acquire spectral components of the signal. While computing THD fundamental frequency is the one from frequency vector defined at the beginning of the measurement but only frequencies larger than excitation limit frequency are used as harmonics in THD formula. That is for exclusion of base excitation component in corresponding amplitude. THD is thus computed for every frequency in defined frequency vector. Finally, average THD value for every batch is computed as output of this algorithm.

4. Experimental setup

Experimental setup consists of LDS V830 shaker with steel mounting plate, aluminium testing frame and tested component. Testing frame is mounted on steel plate and serves for attachment of tested component, which is in form of plastic container.

During experiment white-noise is generated using Polytech software and through amplifiers delivered as an input to the shaker. Three-axis accelerometers of IEPE standard (from B&K and PCB manufacturers) are attached to several parts of the assembly and their signal is processed by NI PXIe system with PXIe-4497 measurement card.

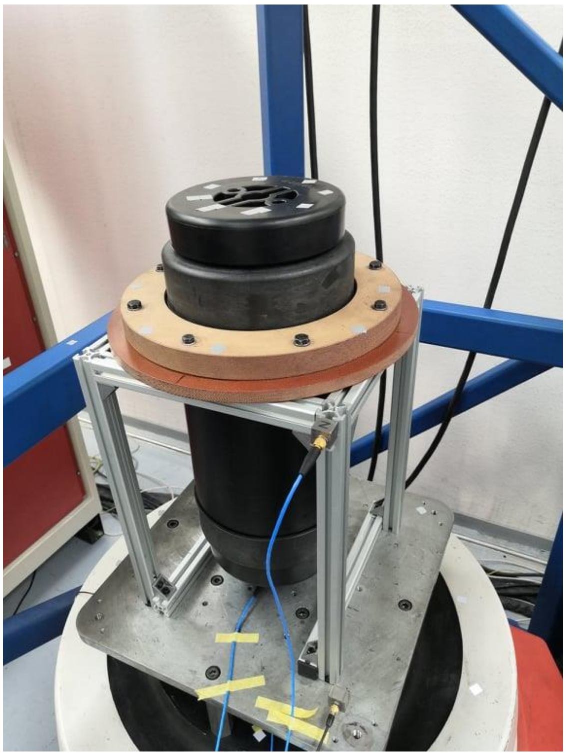

Fig. 1. Vibration testing assembly

5. Experimental results

For THD computation only vertical axis measurement of one accelerometer BK 4056 is used. White-noise with 10 m/s^2 prescribed acceleration and 10-2000 Hz frequency range is used for excitation. Sample rate for measurement is 100 kHz. Experiments are performed in 4 different configurations. They differ in assembly configuration and manner of simulated damage. The algorithm is used on premeasured data.

1st experiment: Fig. 2 - Only steel plate is mounted on shaker's armature. After 60 seconds of measurement two screws on the plate are tightened.

2nd experiment: Fig. 3 - Steel plate and aluminium testing frame are mounted on shaker's armature. After 60 seconds of measurement one screw on vertical beam of testing frame is tightened.

3rd experiment: Fig. 4 - Steel plate and aluminium testing frame are mounted on shaker's armature. After 60 seconds of measurement two screws on aluminium plate are tightened.

4th experiment: Fig. 5 - Complete testing setup (Fig. 1) is assembled (steel plate, aluminium testing frame and tested component). After 200 seconds of measurement one screw on vertical beam of testing frame is loosened.

Noticeable change in computed values are observed after tightening/loosening the screws in all scenarios.

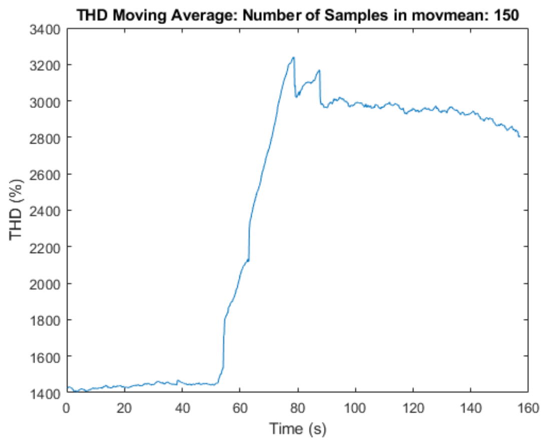

Fig. 2. Moving average of THD during 1st experiment

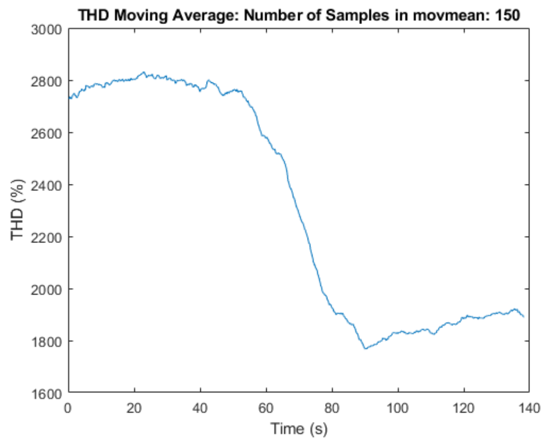

Fig. 3. Moving average of THD during 2nd experiment

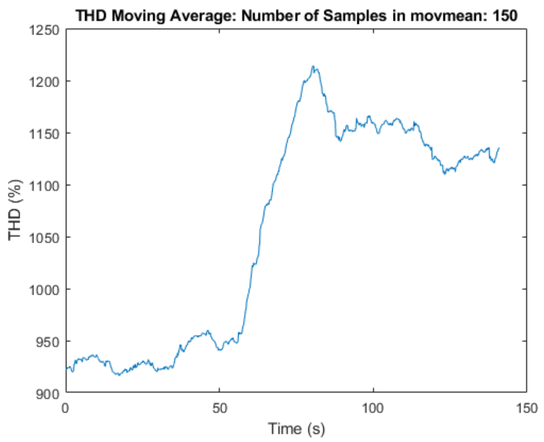

Fig. 4. Moving average of THD during 3rd experiment

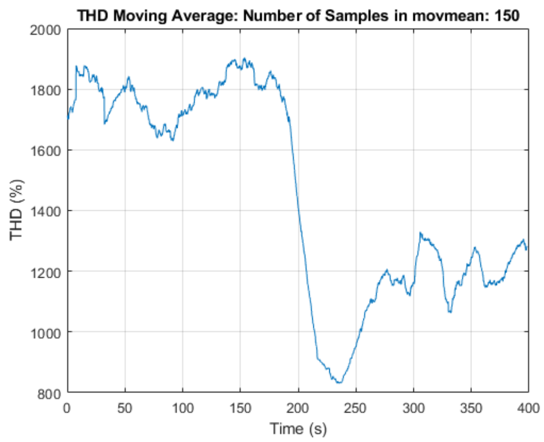

Fig. 5. Moving average of THD during 4th experiment

6. Conclusion

Method for SHM during vibration testing suitable for white-noise excitation is proposed. Based on several experiments noticeable changes in computed average THD values are observed. In four experiments it's 114%, 36%, 24%, 33% respectively.

Future work plan contains real-time implementation, other means of damaging the structure, using data from more accelerometers and axes while performing more experiments in different conditions. This work needs to be done to make the method robust and reliable, but first results seem to be promising.

Acknowledgements

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References

[1] Broch, J. T., Mechanical vibration and shock measurements, Bruel & Kjaer. K. Larsen & Son, Soborg. 1984.

[2] Fan, G., Li, J., Hao, H., Vibration signal denoising for structural health monitoring by residual convolutional neural networks, Measurement 157, 2020.

[3] Miláček, S., Měření a vyhodnocování mechanických veličin, ČVUT, Praha, 2001. (in Czech)

[4] Minderhound, J., A Method for shaker validation, Webinar presentation of Vibration Research Corporation.

[5] Toh, G., Park, J., Review of vibration-based structural health monitoring using deep learning, Applied Sciences 10 (5) 2020.