ON VIBRATION EXPOSURE MONITORING AT INDUSTRIAL INTENSIVE POLLUTANT AREAS

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Abstract. *Main objective of this study consisted by identification, evaluation and characterization of a direct linkage between the vibration levels at the intensive pollutant industrial sources and the vibration exposure of the proximity areas of these sites, at potential sensitive destinations. This analysis acquires high significance when nearly of these industrial sites there are the civil constructions, with preponderant human activities, or habitable areas. Based on a lot of instrumental measurements and using virtual instrumentation applications set, with implementation of the multipoint spectral analysis method, the authors succeeds to dignify the potential influences regarding the certain industrial vibratory pollutant sources and their qualitative effects on destination points, from the direct influence area of the respective sources. The actual benefit of this global approach in exposure evaluation method helps identification and analysis of this particular phenomenon of transmissibility. The instrumental tests were performed at the ASTRA Factory, Arad, Romania, on the forges sector, and on proximity zones.*

Keywords: *Vibration, Exposure Monitoring, Instrumental tests, Multipoint spectral analysis, Virtual Instrumentation.*

1. INTRODUCTION

The development of human and industrial activities has a negative side, denoted by environment pollution with a large variety of sources and shapes, such as chemical dump goods, acoustics sources, vibration, drosses, a.s.o. These affect one or more component of the environment. For this study, is important to evaluate the noise and vibration pollution degree, on industrial areas, besides of human habitation. Finally, it will be reducing to a complete set of practical rules, after which the implementation of the risk reduction will be significant.

The vibration pollution becomes a high important environmental factor in our days, because of the high rate of industrial development all over the world. Obvious, this takes different levels as a function of the specific industrial activities. In case of the industrial sectors with intensive dynamic action equipments, (e.g. mould hammers, forge hammers), it is necessary to acquire, monitoring, processing and analyzing these actions and theirs main parameters, both at the pollutant source, and at the potential receivers (e.g. civil buildings, private houses, educational places). The vibration may be continuous (with magnitudes varying or remaining constant with time), impulsive (such as in shocks) or intermittent (with the magnitude of each event being either constant or varying with time).

On the whole of the technical problems that appear and have to be solved, two of them necessitate more attention: the synchronization on the signals acquisition procedure and the analysis or evaluation of nonlinear technical systems. First problem, of synchronization, appear when the source and the destination are relative secluded, and the acquisition system not furnish wireless or others special capabilities to simultaneous acquire multiple signals. The second problem is more complicated because of the large variety of the nonlinear mathematical models and the heaviness in modeling and simulation of the technical systems taking into account the nonlinearities of these. In Fig. 1 it was depicted a schematic diagram that shown the complexity of the propagation phenomenon of vibration transmissibility between the pollutant source and the potential receivers.

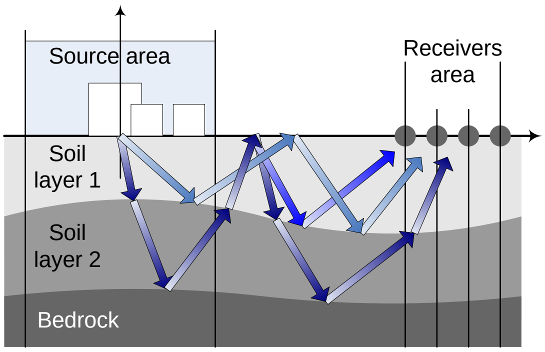


Fig. 1. Schematic diagram of ground vibration propagation.

According to these potential problems, one of the solutions consists by the global evaluation of the source and the receiver status. Simple and direct computing of Cross-Correlation, Cross Power Spectrum, Frequency Response Function, Transfer Function or Coherence Function is not fully recommended because of absence of synchronized measurements. On the other side, the multiple inputs and, in some cases, the multiple outputs, the nonlinearities of different elements, leads to the main idea according to the Point-to-MultiPoint (PMP) topology is more easy to use that mesh topology. A middle way for the complex and fuzzy defined systems could be Multi-Input-Multi-Output (MIMO) methods, but it could be verify that, in many cases, it's very difficult to indicate the real number of the inputs / outputs and to evaluate the expressions of in-out linkages array.

2. THEORETICAL ASSESMENTS

Obviously, the achievement of vibration map for a certain topic area can be supposed as a circular shape with the center toggled in a signal source (or approximate, for a group of closed sources), and with radius dimension correlated with the source characteristics (as power, distribution mode, foundation type, isolation solutions, a.s.o.), the destination characteristics (distance from a source, structural composition, foundation type, isolation solutions, a.s.o.), and the characteristics of medium between these two points (see Fig. 2.a).

A very simple way to qualify and evaluate this case is to acquire the signals, both from the source, and from a matrix of destination points. After that, it will be estimates the transfer functions between the source and each measure point. With the other words, it will be obtained a set of transfer characteristics thus that, for whatever wanted point of destination, the estimation of the vibration level will be reduced on an unsophisticated weighted operation of the source characteristic. All of these data, a final complex mixture of experimental and theoretical values, will be toggled on a diagram, on which will be marked out the iso-level curves.

The main problem of this method consists by the evaluation of the particular aspects of the medium, concerning its influences on the signal propagation. The explanation of supposition regarding the transfer function utilization, provide from the capability of a complete way to describe a dynamic state for a certain system. Thus, the transfer function, through its zeros and poles, is able to estimate both the local, and the global information about the tested system. For multiple degree of freedom systems - like it is in this case - the zeros of the transfer function contain the local information about the mass, damping and stiffness. This fact lead to an easy way for locates and qualifies the singularities in analyzed medium, in this case, the terrain, with all the obstacles, between the source and the receiver points (see Fig. 2.b). Considering the poles of the transfer function, it could be described only the global state of the system, because it exist in all the components of the transfer matrix and are affected by any changes of system parameters.

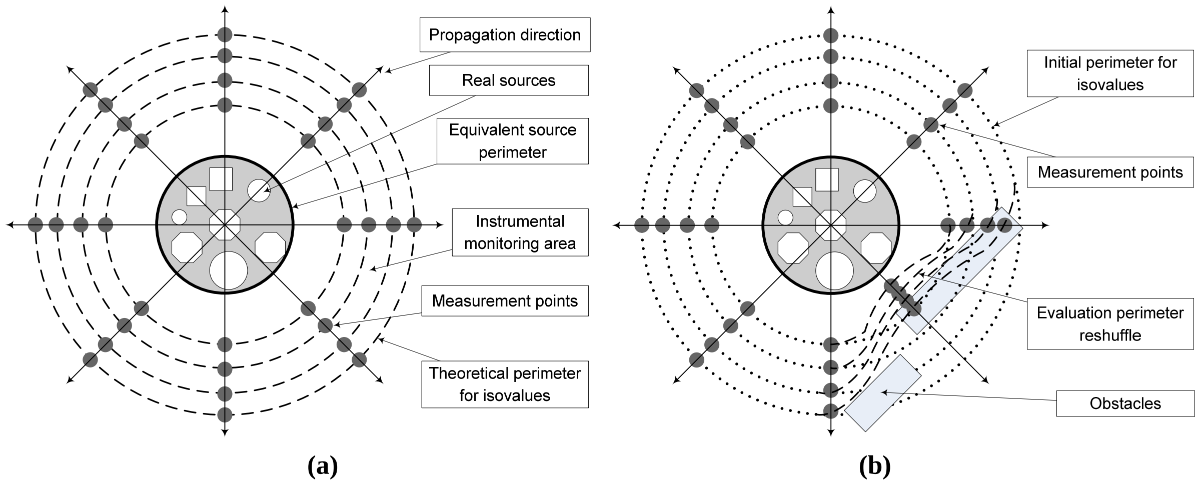


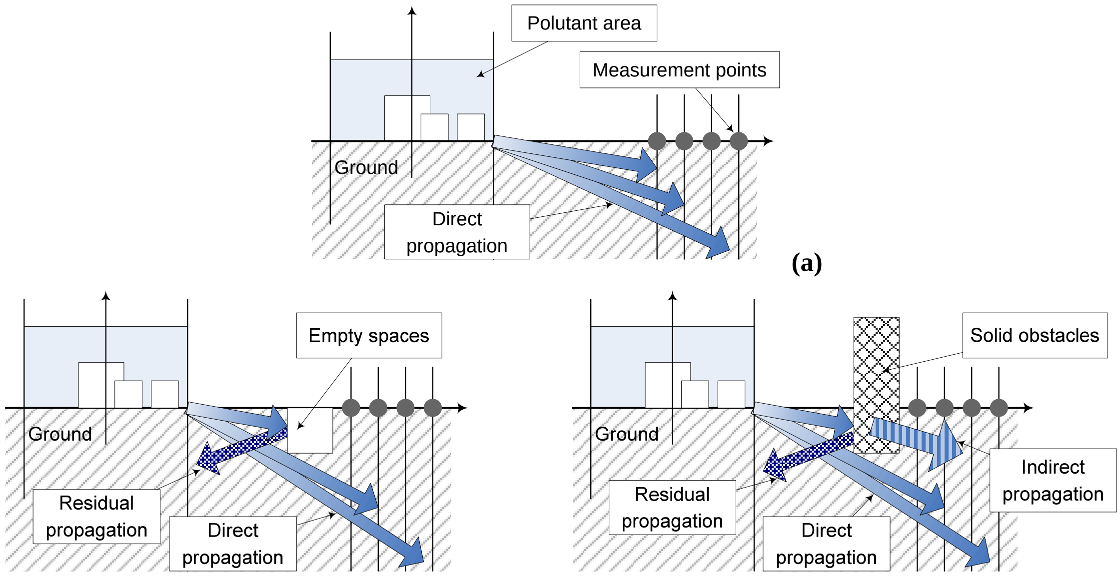
Fig. 2. Schematic diagrams for vibration propagation monitoring (horizontal view):
(a) theoretical diagram for source-receiver balanced propagation case,
(b) monitoring perimeter reshuffling for unbalanced propagation case.

The author consider that a complex evaluation of transfer function matrix, both between the source and each receiver, and from one receiver point to the rest of them, create a complete database of measurements, and starting of these, it could be possible to generate the most closeness and precisely map (Fig. 3). The justification of this new hypothesis is based on the fact that, between any two successive measure points, the computing of numerical values will be made with help of realistic and unequivocal mathematical formula, even this have a numerical formulation.

The primary gain of this complex approach is partial or total elimination of the subjectivity from the intermediary point's evaluation process, and obviously, a high degree of reliability for final map (vibration iso-level diagram).

As a potential solution for analyzing, the *multipoint spectral isolation method* is a combined method from *multipoint* techniques, *spectral* theory, *isolation* and cutout the interesting areas. Briefly, this method is a mixture of procedures, orderly in the next sequence

- *timing acquire* of the acceleration signals at the sources and the receiver;
- *computing* the *spectral composition* of the acquired signals;
- *filtering the signals*, by using the narrow band pass filter, with manual selectable cutoff limits;
- *cutting out* a significant length from the signal (from time-domain evolution), and rigorous processing this;
- *liken the spectral composition* of the source with that of the receiver, and detect the common parts of these.



(b) (c)

Fig. 3. Schematic diagrams for vibration propagation monitoring (vertical view): (a) balanced propagation; (b) unbalanced propagation due to empty spaces (cavities); (c) unbalanced propagation due to solid obstacles.

Running over the procedures sequence, results that this method are based on the Correlated-Spectral-Identification (CSI) technique, completed by classical procedures for spectral functions evaluation. CSI technique means actually the mixed procedure of filtering and cutting of significant parts from the two liken signals. This method is based on the supposition that the noises are additive and the Signal-at-Receiver (*Y*) could be written as:

$$Y(i,j) = N_1(i,j) + N_2(i,j) + X(i,j), \tag{1}$$

where $Y(i,j)$ is the signal at the receiver, $X(i,j)$ is the source signal, $N_k(i,j)$, k=1...2, are the noises at the receiver site, *i* denote the frequency index, and *j* represents the frame index on Fourier Transform. Supposing in expression (1) that noises N_k will be affects the system as a singular input signal, and the system have a unique major input that could affect the output, it is obvious that we have to do with a double input system.

In this particular case, the Coherence functions could be estimate by:

$$\gamma_{iy}^2(\omega) = \frac{\left|H_1(\omega)G_{11}(\omega) + H_2(\omega)G_{12}(\omega)\right|^2}{\left[G_{11}(\omega)\right]\left[G_{yy}(\omega)\right]}, \tag{2}$$

$$\gamma_{2y}^2(\omega) = \frac{\left|H_1(\omega)G_{21}(\omega) + H_2(\omega)G_{22}(\omega)\right|^2}{\left[G_{22}(\omega)\right]\left[G_{yy}(\omega)\right]}. \tag{3}$$

where G_{yy} denote the output PSD; G_{ii} denote the PSDs of the inputs; G_{iy} denote the Cross-Power Spectral Density functions; G_{ik} denote the Cross-Power Spectral Density functions of the inputs; H_k denote the transmissibility function; H^*_k denote the complex conjugate spectrum of transmissibility function. If the inputs are correlated, the expressions of the terms in previous Coherence equations (2), and (3) becomes

$$G_{yy}(\omega)=\sum_{i=1...n}\sum_{k=1...n}H_i^*(\omega)\cdot H_k(\omega)\cdot G_{ik}(\omega) \tag{4}$$

and

$$G_{iy}(\omega)=\sum_{k=1...n}H_k^*(\omega)\cdot G_{ik}(\omega), \tag{5}$$

3. INSTRUMENTAL TESTS

In this paragraph was briefly presented a real case analysis for a major pollutant shock and vibration source from a factory, to a sensitive receiver situated next to the factory site. In Fig. 1 is presented the schematic diagram of the measurements sites, relative to the source and the receiver. Such as it was mentioned in the abstract, the instrumental tests were performed on site of ASTRA Factory at Arad, Romania. The main objective was to provide a serious and decisive proof for the absence of the negative and perturbing effects, due to the forge sector activities, on a private house area situated on a side, nearby the factory domain limit. The other objective of these tests comes to furnish a practical example for theoretical aspects presented on the previous paragraph.

Both at the source, and at the receiver, it was made a set of tests about adequate settlement of vibration sensors - for better signal acquisition on given situation, especially at the receiver place, where the signal level was very low and the ratio between signal and background noises acquire a high values. The emplacement of the measure points was performed hereby: *at the source* - on the concrete foothold of the forge sector, lined up with the propagation direction, at the 3 m distance from the vibration source, and on the vertical direction; *at the receiver* - on the first floor of the building, into the living room and into the bedroom of the house.

In Fig. 4 it is depicted the source signal, measured nearby the shock and vibration generator (mould hammer pathway), on a grounded solid state metal block. Analyzing these diagrams, it could be observed that area of interest is toggled between 20 and 40 Hz, with some relative irrelevant peaks up to 80 Hz.

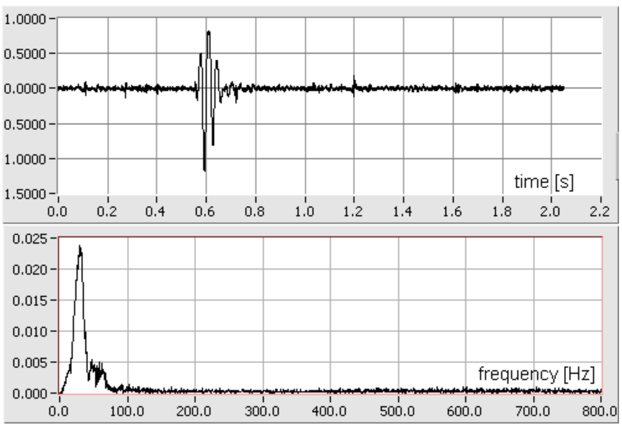


Fig. 4. The signal of the source acquired at 3 m nearby the mould pathway top: time-domain; bottom: PSD.

In Fig. 5 it is depicted the background noise measured at the receiver, in the absence of the tested sources. There is evident on the diagrams that the 0...100 Hz is the area of interest in this case. Some irrelevant peaks covers the area from 150 to 180 Hz, but the relative magnitudes of these indicates a slightly influence on global perception.

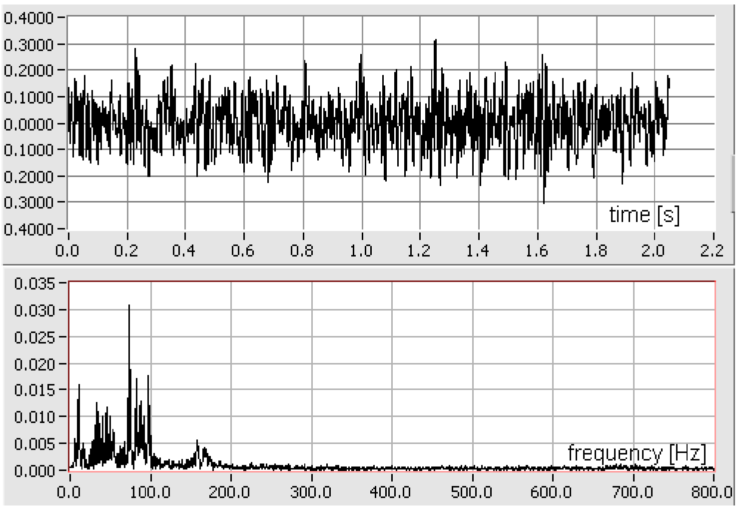
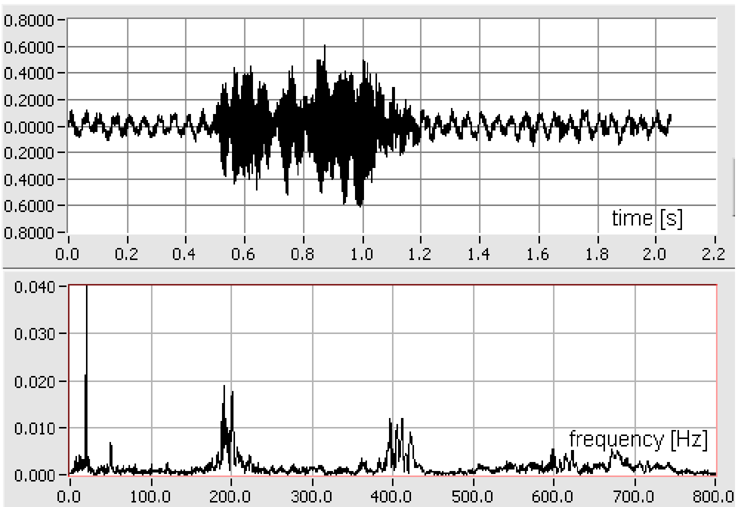
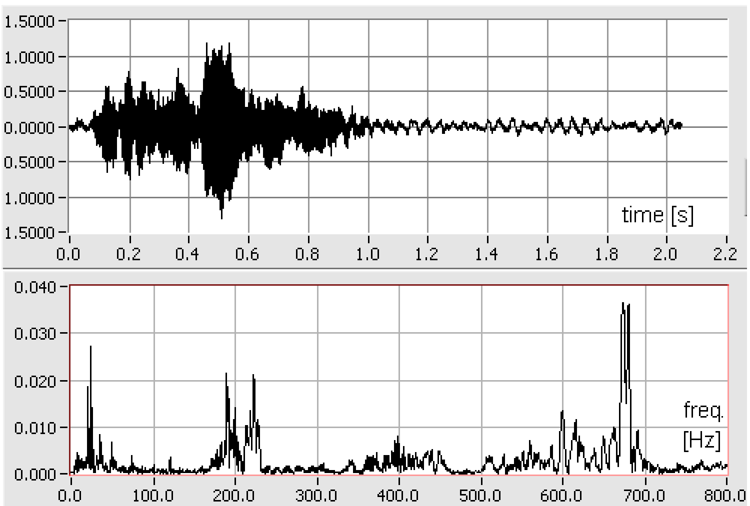


Fig. 5. The signal of the background noise acquired at the receiver top: time-domain; bottom: PSD.

In Fig. 6(i) it is depicted the signal measured at the receiver, with normal working state for the tested vibratory sources. In Fig. 6(ii) it is presents another set of measurements at the receiver, on the same place as the previous case, and with approximate the same conditions at the sources.



Case (i) - living room, first floor of building



Case (ii) - living room, first floor of building

Fig. 6. The signal at the receiver; top: time-domain; bottom: PSD.

4. DISCUSIONS AND CONCLUDING REMARKS

The multipoint spectral analysis method - based on correlated spectral identification technique, become a real choice for dynamic technical systems identification and evaluation, especially in absence of enough and/or adequate data for usual analysis. This method could be also used, as in the presented case, when the instrumental tests were not providing a synch and parallel acquisition procedure. Other cases of serviceable using of this method are when the experimental data derived as a result of a statistical procedure applied on sets of measurements in the same testing condition, or derived from a temporal or spatial averaging procedures applied on multivariable functions.

On the whole, note, that for this procedural application, the phase information for whatever the estimated essential parameters, are not decisive, because of synchronization missing on signals acquire process.

The multipoint spectral analysis method was started from an empirical technique and it has been used successfully, for different behavioral analysis and evaluations of technical systems dynamics. This method could be used as an estimative tool for simple and fast estimation of source-destination correlation, but it could be also used - and it is recommended - for precisely and accurate qualitative and quantitative evaluation of linkage between dynamic pollutant source and sensitive receivers. This last kind of applications needs virtual instrumentation implementations to increase the accuracy and reducing the processing time.

Its evident the fact that a vibration map, such as the noise pollution map, has a local application, only for the area and for the structure and state conditions, which it was analyzed. Thus that, the necessity of a practical and simple methods development is provided and sustained by the large area of industrial activities, with a direct and powerful impact on environment risk reduction.

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