SELECTED DIAGNOSTIC ASPECTS OF PROPAGATION OF VIBROACOUSTIC ENERGY[1]

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Summary

Methods based on diffusion of vibroacoustic energy play a particular role in solving practical engineering tasks, including evaluation of the object's state, improvement of user's comfort, and shaping the acoustic atmosphere. The way of propagation of noise and vibration often determines the functional advantages of a technical object.

One of the reasons why the detectable changes in vibroacoustic signal appear can be modification of ways of propagation caused by damages or exploitation wearing. Studies on these problems comprise also search for the measures susceptible to the changes of the object's state, based on analysis of propagation of vibroacoustic energy. The discussion is illustrated by two cases.

Keywords: noise, vibrations, vehicle.

WYBRANE ASPEKTY DIAGNOSTYCZNE PROPAGACJI ENERGII WIBROAKUSTYCZNEJ

Streszczenie

Metody bazujące na rozprzestrzenianiu energii wibroakustycznej odgrywają szczególną rolę w rozwiązywaniu praktycznych zadań inżynierskich między innymi dotyczących oceny stanu, poprawy komfortu użytkowania, oraz kształtowania klimatu akustycznego. Sposób propagacji drgań i hałasu często decyduje o walorach funkcjonalnych obiektu technicznego.

Jednym z powodów rozróżnialnych zmian sygnału wibroakustycznego może być modyfikacja dróg propagacji bezpośrednio spowodowana uszkodzeniem bądź zużyciem eksploatacyjnym. Badania tych aspektów obejmują poszukiwania miar wrażliwych na zmiany stanu obiektu bazujące na analizie propagacji energii wibroakustycznej. Rozważania zilustrowano dwoma przykładami.

Słowa kluczowe: hałas, drgania, pojazd.

1. INTRODUCTION

Studies of propagation of vibroacoustic energy play a particular role in solving practical engineering tasks, including evaluation of the object's state, improvement of user's comfort, and shaping the acoustic atmosphere. Actually, it is propagation of vibroacoustic energy that often determines (in a very broad meaning) the functional advantages of a technical object.

The model analysis form an important part of all the studies aiming at optimization of the exploitation process of machines and units. The relations between diagnostic symptoms and technical state have been searched using numeric simulation, without costly and laborious experimental studies. However, it has been found that the results of simulation calculations cannot be directly translate into practical applications: they require the empirical verification as well as the adaptation to technical realities. It concerns also the question of modeling of generation and propagation of vibroacoustic signals: the level of complexity of the phenomena shaping these signals makes unreal any attempt to construct a model fully describing the reality.

The dynamic models of one or several degrees of freedom are often good enough to analyze construction or characteristics of machines and units. The important setbacks start when a non-linear component appears; however, it is in non-linear way that the technical state of objects change [1].

The disturbances in propagation of vibroacoustic energy considered in relation to diagnostic reasoning are also result of non-linearity. A relationship between the damping qualities of the object's structure and the surrounding environment has been

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observed. Therefore, the search for methods that in a relatively easy way could take into account the elements mentioned above seems quite logical.

2. MODELING OF PROPAGATION

Forecasting the frequency structure of vibroacoustic signal received in particular point requires an analysis of input characteristics and ways of propagation of vibroacoustic energy. Assuming that there is a dominating source, the signal received by the observer, treated as a response in the domain of frequency can be written as the following equation [2]:

$$Y(f) = X(f) \cdot H(f) \cdot \Phi^*(f) \cdot \Psi^*(f) \tag{1}$$

In the relationship $Y(f)$ is Fourier's transform of the received output signal $y(t)$, $X(f)$ - the Fourier's transform of the input process $x(t)$, $H(f)$ - transmittance of the propagation way, $\Phi^*(f)$ - an attempt to describe the non-linearity as a product in the identification process, and $\Psi^*(f)$ reflects the influence of external disturbances (noise).

Both sides of the equation (1) can be transformed by operator that transforms the scale into the logarithmic one (decibel). Then the task described by the relationship can be brought to the equation of level decrease:

$$L(f) = L_s(f) + \Delta L_h(f) + \Delta\Phi^*(f) + \Delta\Psi^*(f) \tag{2}$$

$L(f)$ is the input level, $L_s(f)$ - level of dominating source (input), $\Delta L_h(f)$ - decrease (increase) of level resulting from transmittance of the system, $\Delta\Phi^*(f)$ - change of the output level provoked by non-linear disturbances and defined by identification, $\Delta\Psi^*(f)$ - change of level provoked by contingent disturbances, impossible to forecast: this is description error.

The description presented above can be applied under the condition of elaborating it for a particular object and identifying parameters of the model. However, a relatively simple form of the equation (2) reflects certain philosophy that can help developing the efficient reasoning leading to the solution of particular engineering tasks. The following paragraphs present two examples of application. The first case illustrate possibilities of reproducing development of damage using measures susceptible to disturbances of propagation of vibration. The second one reflects the need of deeper analysis of propagation of vibroacoustic energy in construction of noiseless machinery.

3. EVALUATION OF DAMAGE DEVELOPMENT

The discussion is based on the results of testing vibrations forced in truss beams made of compressed concrete in different stages of degradation [3]. The time courses registered with the force processor ($F(t)$, input) and accelerometers ($a(t)$, response) have been used for calculating value of the measures of propagation of vibration energy H_a:

$$H_a = \frac{\int_0^T \left(a(t)\right)^2 dt}{\int_0^T \left(F(t)\right)^2 dt} \tag{3}$$

The formula were discussed in [4], where also the questions of focusing the susceptibility of measure on particular failure by proper choosing the positions of accelerometers and the input excitation points were presented. There was an obvious relationship between the propagation of vibroacoustic energy by the structure of the objects under scrutiny and a failure resulting from overloading.

Synthesis of the results of research on changes of efficiency measures of vibration propagation in function of static loading of two beams are shown in the graph below (fig. 1). The values have been calculated as the average of five changes courses for vibration accelerations in the fixing points of accelerometers and the impulse input processed according to the relationship (3).

If we compare the graph's characteristics with the deflection and the observed stage of brake development, we can see their obvious interrelationship. There was visible increase of deflection [5], under the load of about 35 kN, while high bending stress resulted in the initiation of breaking process. These load values are accompanied by visible in the graph, local trend disturbance in changes of measures of propagation of vibration.

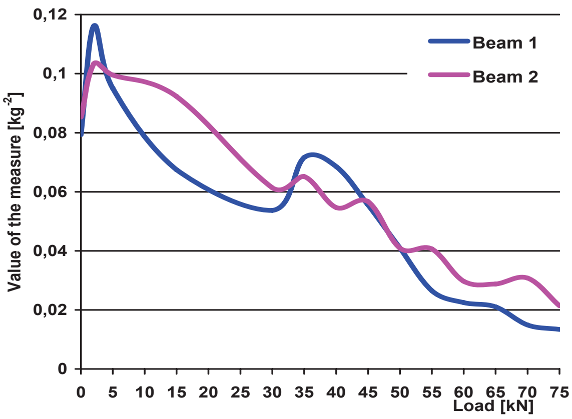

Fig. 1. Changes in measures of propagation of vibration energy in function of load

It seems to be the effect of change in vibration form resulting from non-linearity of structure that modifies the ways of propagation of vibroacoustic energy. Susceptibility of the measures of vibroacoustic energy propagation to structural non-linearity illustrated in the graph is related to the direction of input force which in this case is perpendicular to the direction of load and the breaking surface. The localization of accelerometers makes the wave spreading in the structure after the impulse input pass the particularly damage-prone zone. Different input direction or another location of accelerometers result in lower diagnostic susceptibility of the measures set according to the formula (3) to a particular damage. Therefore, for the diagnostic usefulness of measures in the context of their susceptibility for structural non-linearity in the most damage-prone zones it becomes crucial to relate the localization of vibroacoustic signal transducers with the spot and input direction.

4. MINIMIZATION OF VIBRATIONS AND NOISE

The approach has been applied in improving the prototype solutions of power transmission unit of an atypical environment-friendly vehicle. The innovative construction idea and lack of previous experience with similar machines made it necessary to determine main noise sources in the cabin, as well as the ways of propagation of vibroacoustic energy in order to establish noiseless conditions.

Extensive studies applying highly developed measurement techniques, backed with the professional scientific software allowed analysis that let us identify causes of excessive noisiness. As a result, several modifications were suggested, which improved the exploitation conditions of the vehicle.

The key tests of vibrations and noise in the vehicle were carried out in form of passive road experiment on the real object. The attention was put on guaranteeing comparable measurement conditions (mainly velocity). Further stages of testing, designed to verify and improve the methodology include also some active experiments at the laboratory test-bed. They concern basically separate units of the vehicle.

In the experiment the vibrations of selected points on the body of power unit were recorded, as well as the noise in two places within the cabin (near the heads of the driver and of the passenger) during acceleration, with constant speed of 60 km/h and during breaking with the power unit. The set of two accelerators and two microphones collaborating with a portable computer via the measurement module by National Instruments, the computer being programmed in the environment LabView. Time courses were sampled in frequency of 50 kHz. The main elements of the set used in the tests are shown in the diagram in the Figure 2.

Fig. 2. The measurement equipment

While analyzing the results an outstanding propagation of vibroacoustic energy between the power unit and the cabin of vehicle became visible. The interrelationship between the vibrations generated by the main power units (the engine and the two-step belt toothed gear) and noise in the cabin resulted in a detailed identification of the ways of transmission of noise and vibrations.

The main construction element of the vehicle in question consists of closed aluminium profile (load-supporting beam) joined with the power unit using a self-aligning joint. The tests have shown that the construction solution applied determines transmission of vibrations of the whole power unit onto the load-supporting profile. Flat surfaces of the profile become secondary sound sources in the cabin and induce the body vibrations. In this case "cutting" this way of propagation of vibroacoustic energy seems to be necessary (in the spot marked with the red arrow in the diagram below – see Figure 3).

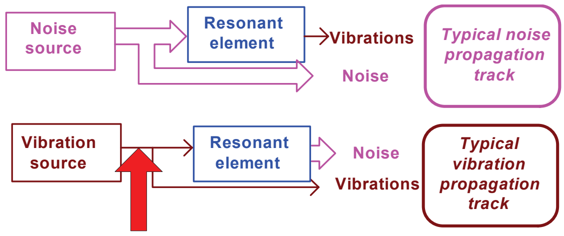

Fig. 3. Diagram of vibrations and noise propagation

The self-aligning joint of the power unit with the main construction element of vehicle should allow rotation in a minor angle range and at the same time stabilize the unit in relation to the two remaining axis. This is what substantially limits the area of possible solutions of minimizing the vibrations transmission. However, it is clear that proper damping elements should be used.

For minimizing the transmission of vibrations from the power unit to the load bearing beam two axially symmetrical elements made of rubber and metal were used, fixed on pins stiffly joined with the body of power unit. The rubber was 75 degrees Shore hard. Having applied the modification the resultant sound level in the cabin dropped (comparable experiment conditions) by more than 6 dB(A) which means more than two times lower amplitude of acoustic pressure.

The applied solution eliminates the main way of propagation of vibroacoustic energy between the power unite and the driver's cabin. However, it does not influence the noise transmitted directly by the air in from of sound wave. To reduce the negative influences in this area we should "cut" the typical way of sound propagation using close soundproof barriers.

5. CONCLUSIONS

The work described in the article is a part of a project aiming at elaborating the methodology of using information contained in the vibroacoustic signal for monitoring vehicles and reducing their noisiness. The results seem to confirm usefulness of the measures of propagation of vibracoustic energy as parameters applicable for evaluating the object's state. At the same time we can see that an extensive analysis, backed by both modeling and experimental research on mechanisms of transmitting vibrations is a proper tool for efficient minimization of vibroacoustic nuisance of machinery.

In spite of complexity of the problems outlined in this article it can be already said that the direction of studies and research has been positively verified. The cases confirm that consistent strategy realized according to the outlined philosophy lead to technical application of assumed parameters.

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