THE PROBLEMS OF MODELLING AND IDENTIFICATION OF SOURCES OF NOISE IN MACHINES

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ABSTRACT The work discusses the problems of modelling of the process of acoustic signal generation in machines.

We have pointed out that in the task of minimizing of both noise and vibration, the key problem is identification of sources and paths of propagation, both in terms of their location and of definition of their characteristic features. Properly conducted identification makes possible the use of relatively simple mathematical models and this fact is particularly important for a broad application of the proposed methods in practice.

The significance of the problem of identification is also increased by the fact that in the models of complex machines (in this work we have used the example of hydraulic excavators) we are practically unable to define many dynamic effects solely in theoretical manner.

Bearing in mind the usefulness of solving tasks formulated in such a way, we have analyzed the possibilities and limitations connected with defining of the criterion of identification in the time and frequency domain.

Let us study a relatively broad group of machines in which the operator's workplace is directly connected with the machine and it constitutes the integral part of the machine's dynamic structure. Examples of such machines are machines used for construction of buildings and roads, and to a certain extent also vehicles. Let us now formulate the task of minimizing of vibration and noise at the operator's workplace. In general we can bring the problem down to the postulate of minimizing of the vibroacoustic activity in a selected point (area) within the machine's structure with, to a certain degree, a possibility of selection of this area . Solution of such a task by means of optimizing techniques requires from us a mathematical model of the machine. This condition, for the above mentioned group of machines, is most often impossible to meet. Thus, what is left is the problem of identification of a model on the basis of measurement of the dynamic functions (of vibration and noise). In order to characterize the task more precisely, let us analyze a general scheme of propagation of mechanical vibration and noise along the path sources - operator's workplace (Fig. 1).

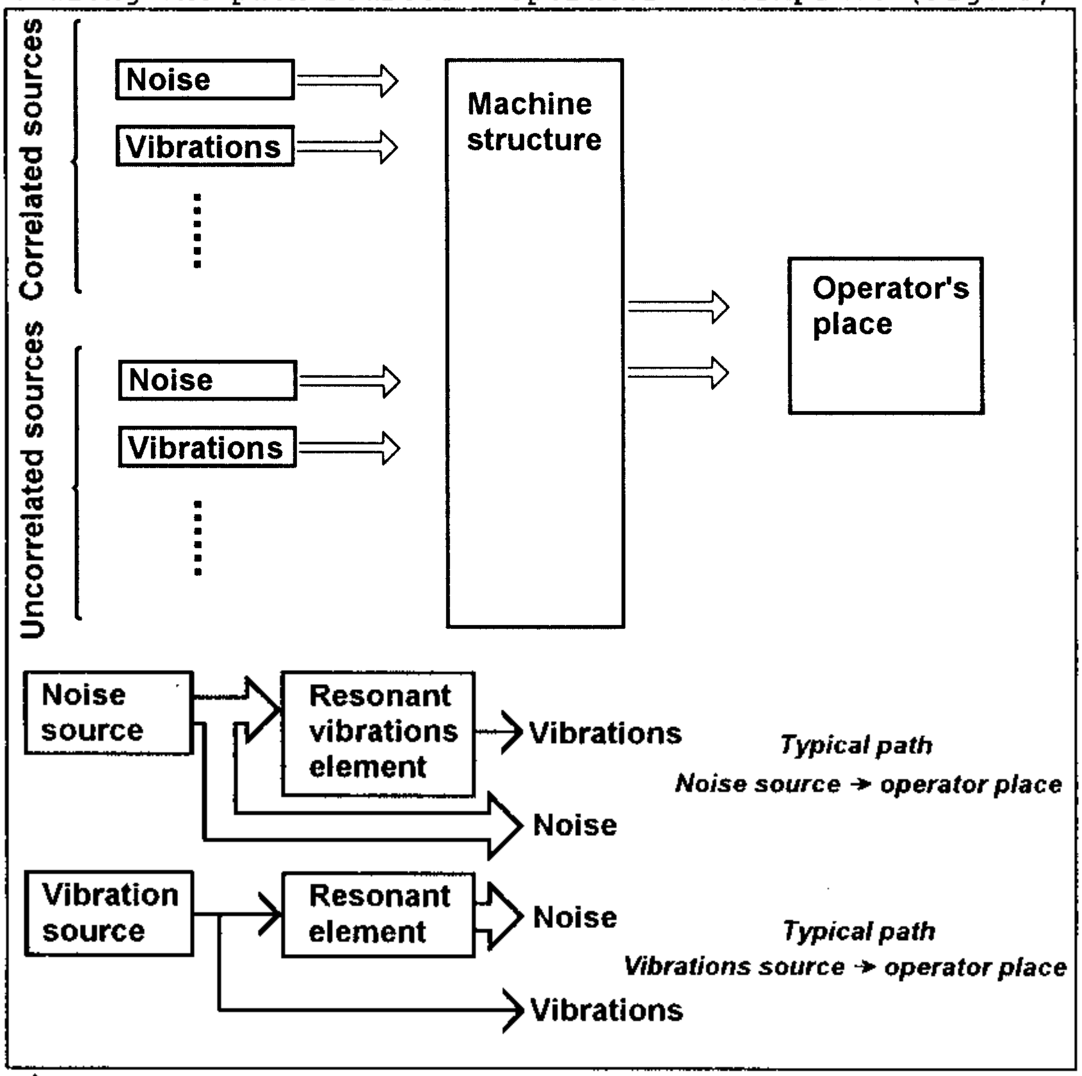

Figure 1

In a machine we usually have *n* sources of vibration and noise which, as a result of the machine's functioning, are to a lesser or greater extent correlated together (for example the engine and the elements of the power transmission system), and a certain group of sources with minimum degree of correlation (for example hydraulic or electric-powered systems, which are controlled independently from the kinematic chain of the main power unit). The main problem lies in the fact of mutual connection between the vibration and noise paths of dissipation of energy. This is due to the fact that in a machine we encounter a whole series of resonant effects, which cause the occurrence of additional sources of noise as a result of magnification of mechanical vibration (for example the side covers) and excitation of mechanical vibration by the energy of the acoustic wave. Additional difficulty lies in the fact that the acoustic field between the parts of a machine is very complicated as a result of numerous instances of interference occurring between the waves reflected by the parts which are often in motion (thus at various angles in various moments of the typical work cycle). In such a situation the first essential difficulty connected with the identification of the model occurs already in the stage of localization of the source of noise. There exist many vector and scalar methods of localizing the sources of noise with complex frequencies on the basis of external measurements [1]. Among the most popular we have: sound intensity measurements using two microphones [2, 3] and definition of the points with a maximum level (the technique of external measurements in *n* points which are equidistant from the machine's center). In the first case the limiting factor is the impossibility of access to many points located inside the structure, and in the second it is the fact that the measured level of noise is in an essential manner transformed by the very structure of the machine. Even in case of surpassing both of these difficulties, we will in the end localize the points of the acoustic field having the maximum level (or intensity) of the noise, and not the physical sources of this noise. Thus, while not negating both of these techniques, we should consider their use rather as an auxiliary method, which makes the study of the complex paths of propagation easier, than as a direct basis for the identification of a model. A practical example of localization of points with a maximum level of noise in narrow bands (2 Hz) with a given mid frequency is presented in Fig.2, which shows the top view of a hydraulic excavator. The physical, original sources of noise (the engine, the manipulators, pumps, fans, etc.) are marked in black. As we can see, the points with maximum levels lie outside of the original sources and most of them change their position for various speeds of the power system.

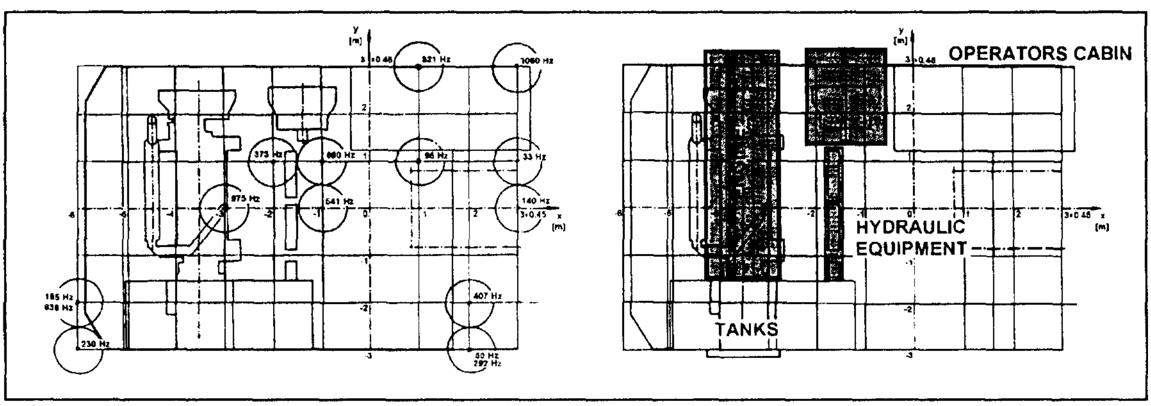

Figure 2

The machine that was examined is by no means an exception and the situation that was described here should be assumed as a rule.
Summing up the above reasoning, it seems most expedient to work out such identification procedures which would enable us to characterize the transition function between the real (physical) source of noise and the place in which the noise and the vibration are supposed to be minimum.

The relationship between the input and the signal measured in a chosen point can be noted in the following way for most dynamic systems [4]

$$S_t\{x(t)\} = \sum_n p_i(t,\ldots) * h_i(t-\tau,\ldots) + \varphi(p_i, h_i, t) + \psi \quad \textbf{(1)}$$

where

$p_i(t,\ldots)$	-	input
$h_i(t-\tau,\ldots)$	-	function of transition
$\varphi(p_i, h_i, t)$	-	function accounting for the mutual influence (the degree of correlation) of various inputs and functions of transition (i.e. for a non-linear system)
ψ	-	noise related to measurement
S_t	-	the operator of averaging in time and (or) the selection of the measured signal symbolizing the signal's initial processing.

If it is possible to isolate sources which are independent from each other (for example by means of correlation analysis), then we can treat each group of correlated sources as one source, and then by making an assumption of work in stationary conditions and by subjecting both sides of equation 1) to Fourier transform we can bring the problem down to the following relationship:

$$S_\omega X = \sum P(\omega,\ldots) \cdot H(\omega) + \Psi \quad \textbf{(2)}$$

In this case the function $\Phi = \mathscr{F}\varphi = 0$, and Ψ denotes the spectrum of a noise event. S_w denotes the selection operator in the frequency domain, the use of which makes possible the elimination from the model that is being identified of these fragments of the spectrum, in which we are not interested. In fact the use of the above mentioned operator can be much broader (for example selection of various measures) [4].

Approaching the problem in accordance with the proposed rotation makes identical notation of the problems of propagation of noise and vibration possible, but in accordance with our earlier reasoning the dependence of the vibration path upon the noise path requires introduction of a non-zero value of the function $\Phi(P_i, \omega)$.

Let us now examine the problem of identification upon the example of propagation of noise between the main source of noise that is the power unit, and the workplace of the operator in case of a hydraulic excavator (Fig.2). Let us assume that the model will serve the purpose of selection of optimum acoustic parameters of the shield of the engine. Let us assume a function of transition $H(\omega)$ having the following form:

$$H(\omega) = \bigcap_{i=1}^{5} H_i(\omega) \tag{3}$$

where

H_1 - acoustic transmittance of the projected shield

H_2 - acoustic transmittance of the space between the engine and shield

H_3 - acoustic transmittance of the space between the engine casing and the wall of the operator's cab

H_4 - acoustic transmittance of the space within the operator's cab

H_5 - acoustic transmittance of other paths of propagation

The values from H_2 to H_4 can be calculated in theoretical way, while the value H_5 is the natural parameter of identification during simultaneous measurement of the input and output of the system without the H_1 shield (it is a parameter which compensates for the errors of all the calculated values). Substituting the noise component in equation 2) with a proper multiplier of the transmittance function and using to the logarithmic scale of levels we can obtain a simple algorithm having the form of a series of vectors, which have as many coordinates each as the number of bands in which we conduct the analysis [3, 5].

The drawback of the presented procedure is its limitation to stationary motion. In a real work cycle the acoustic characteristic of the source and sometimes also the transmittance H_5 vary or a random processes (depending upon the load of the machine). Thus, if we want to utilize the discussed model for defining the optimum characteristic of the designed shield, then we should conduct n acts of identification and optimization for various conditions of work, and then select the characteristic on the basis of the statistical analysis of the frequency of occurrence of individual components of a work cycle. If we have a normal distribution, then it is much better to use the model of autoregression (ARMA) [6, 7]. If we assume that a cycle of work of a machine consists of short periods of stationary work (which is correct for a conventional group of machines), then we can assume that the random process $\{x(t)\}$ is a discrete process, and instead of subjecting both sides of equation 1) to a Fourier transform, we subject them to a "z" transform, obtaining as a result the formula for the impulse transmittance [8].

$$H(z) = \frac{P(z)}{X(z)} \tag{4}$$

in which $P(z)$ and $X(z)$ are defined by the ARMA models for n observations and this fact eventually leads to the following procedure:

$$H = \mathscr{F}\{Z^{-1}H(z)\} = \bigcap_{i=1}^{n} H_i \Rightarrow H_1 = \frac{\mathscr{F}\{Z^{-1}H(z)\}}{\bigcap_{j=2}^{n} H_i} = H_1(\omega) \tag{5}$$

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