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REDUCTION OF LOW FREQUENCY NIOSE EXCITED BY ROTARY TYPE EQUIPMENT, WITH THE HELP OF ADAPTIVE SYSTEM

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Opportunities of reduction of low-frequency noise excited by industrial and transport equipment, up to required norms by traditional passive means are rather limited. These limits are especially important, as practically there are no reserves to increase the weight of passive means and the volume for their stationing in transport objects such as ships, planes, etc. The unique alternative to passive means is the active noise protection means. The principle of active system work is creation with the help of a loudspeaker or loudspeakers an additional sound field, which in the given points of control reduces an initial field excited by machines and mechanisms. The active means supplement the passive ones, expanding the frequency range of effective noise reduction to lower frequencies.

The results of working out and testing one-channel adaptive system for active reduction of noise excited by rotary type industrial and transport equipment are given in this report. The machines, such as the electrical and diesel generators and engines, internal combustion engines, reducers, pumps, compressors, fans, turbines as well as other noise sources which are characterized by repeating in time cycles are related to this kind of equipment. Noise produced by these sources, can be described by the determined polyharmonical model rather precisely in a number of cases. In other cases it should be considered as a random process. Let's illustrate it with some examples.

The working electrical generator excites the most intensive noise radiation at rotation frequency. With increase of harmonic number the intensity of radiation quickly falls down. In this case the periodic model describes such noise most adequately. When several asynchronous engines of one type work simultaneously and its loading changes randomly and independently, noise can be described rather well by stationary random narrow-band process. When diesel or internal combustion engine works, its noise can be represented as the sum of harmonics of the basic rotation frequency of mechanism, the amplitudes of which weakly fade with increase of their number. In this case noise can be considered as periodic signal or stationary random broadband process.

The adaptive control algorithm is worked out for each of the described above cases. The complexity of the control algorithm depends on the complexity of the signal mathematical model essentially. Good correspondence between the control algorithm and the signal model leads to the best technical and economic characteristics of the adaptive system. These algorithms are realized on the basis of digital computing unit with analog-digital and digital-analog converters for data input-output.

Fig.1 presents the structure of one-channel adaptive system (**AS**) intended for reduction of noise excited by the controllable primary sources **PS,** for example, several rotary type mechanisms, installed on the construction. There are also uncontrollable sources **US –** set of mechanisms and other sources of various origins that create the other component in initial field, an impediment for the system functioning, which cannot be or should not be reduced.

On the circuit one can also see electro-acoustic converters – the control microphone **M** and the loudspeaker **L**, as well as the basic receivers **BR** which in a number of cases are absent, and the control unit **CU**. The loudspeaker **L** produces the secondary field while the basic receivers **BR,** installed directly on the primary sources **PS** or near to them, are intended for control and transfer the information of these source signals to the control unit **CU**. The control microphone **M**, installed in the given point of "zone of silence", receives the information about resulting field as the sum of the initial field, produced by the primary sources **PS,** and the secondary field, produced by the loudspeaker **L,** and transfers it to the control unit **CU**. The basic receivers **BR** and the control microphone **M** are connected with the control unit **CU** through appropriate preamplifiers **P** and the power amplifier **PA**. The drive loudspeaker **L** signal $x(t)$ is synthesized in the control unit **CU** on the basis of the basic receivers **BR** signals $s_1(t), s_2(t), ..., s_k(t)$, the control microphone **M** signal $y(t)$ and characteristics of the control object (**CO**) – series connection of a the loudspeaker **L**, the control microphone **M** and sound medium between them,. Thus it is supposed, that the characteristics of the control object **CO** are measured by the system automatically prior to the beginning of adaptive process.

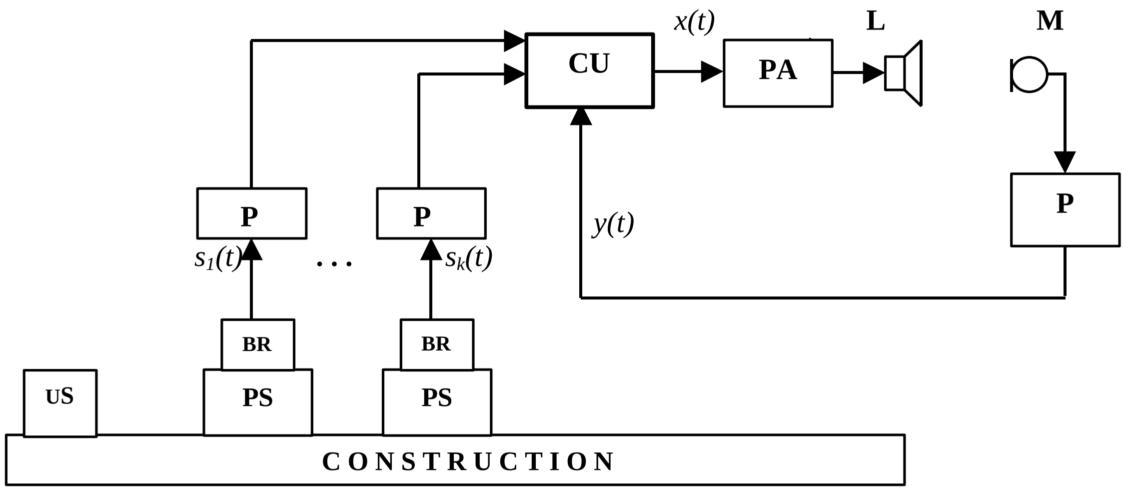

Fig.1.

The **AS** structure above considered is described by the equations in assumption of system linearity:

$$y(t) = d(t) + \mathbf{A}x(t), \tag{1}$$

$$x(t) = \mathbf{W}y(t), \tag{2}$$

where $d(t)$ – the signal of initial field raised by the controllable primary sources **PS** and the uncontrollable sources **US**; $\mathbf{A}$ – the operator of the control object **CO**; $\mathbf{A}x(t)$ – the signal of the secondary field produced by the loudspeaker **L**; $\mathbf{W}$ – the operator of the control unit **CU** (the control algorithm), dependent on the operator $\mathbf{A}$ and, generally, on the basic receivers **BR** signals $s_1(t),s_2(t),\dots,s_k(t)$.

The function circuit given in fig.2 corresponds to the equations and evidently reflects connections between **AS** elements.

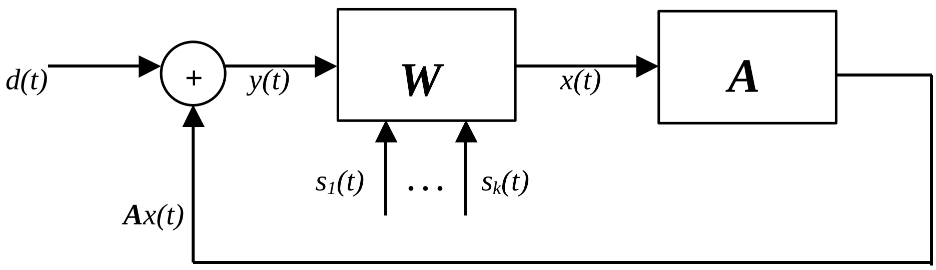

Fig.2.

On **AS** synthesis the problem of noise reduction is put as follows: for the given (measured) signal $d(t)$ and the operator $\mathbf{A}$ to find such operator $\mathbf{W}$, which would reduce the norm

$$7\, y(t) 7 = 7\, d(t) + \mathbf{A}x(t) 7 \tag{3}$$

of the control microphone signal $y(t)$. Then the problem of noise reduction is brought to approximation of the initial field signal $d(t)$ by the secondary field signal $\mathbf{A}x(t)$ with opposite sign. Thus **AS** can be considered as a servo system of automatic control, the input of which is the initial field signal $d(t)$, the output – the secondary field signal $\mathbf{A}x(t)$, and the control microphone signal $y(t)$ which should be reduced by the system, is the control error signal. Purpose of any servo system of automatic control, including **AS**, is to reach the lowest level of the control error signal $y(t)$ at possible changes of the input initial field signal $d(t)$ and the operator $\mathbf{A}$.

If the value $7\, y(t) 7$ tends to minimum, then **AS** is optimal. In the modes of polyharmonical and stationary random broadband noise reduction in works [1,2] and [3,4] correspondingly adaptive optimum control algorithms – the operators ***W*** in the ratio (2), are found. The algorithms ensure optimum noise reduction in sense of the root-mean-square signal *y(t)* minimization. In the first case an orthonormal basis is synthesized from harmonics, frequencies of which are equal to frequencies of noise harmonics. Then the control microphone field signal *y(t)* is analyzed and the drive signal *x(t)* is synthesized in this orthonormal basis. In the second one the adjustable non-reqursive (FIR) filter is used for formation of the drive signal *x(t).* Coefficients of this filter are adjusted according to known adaptive control algorithm of root-mean-square value [5]. The optimum **AS** realization requires to use the nonlinear basic receivers insensitive to the action of the primary and secondary sources, to which the basic receivers are not connected. Examples of designing of such basic receivers are given in [4,6].

The numerous experimental tests of **AS** intended for reduction of noise excited by rotary type equipment with various control algorithms, confirmed that the noise harmonics level dropped up to the level of distributed interference noise created by uncontrollable sound sources in a frequency analyzer band pass. For estimation of the achievable efficiency of noise reduction the level of such interference noise was chosen as the least within the limits of possible.

When reducing polyharmonical noise excited by such mechanism as the electrical generator with rotation frequency ~50 Hz, the efficiency of three first harmonics reduction reached 50 dB.

The tests of **AS** in the mode of stationary random broadband noise reduction were carried out also. The signal of the initial field excited by a rotary type mechanism such as a diesel engine, represented a sequence of ~3 mc width pulses with frequency of following ~42 Hz. Fig. 3 shows the resulting spectrogram of noise reduction. In the frequency range up to 250 Hz the efficiency determined as the difference between the initial level of harmonics and the level of the distributed interference noise created by uncontrollable sound sources, was not less than 35 dB. One can consider that all noise harmonics were reduced practically completely in the mentioned frequency range. When increasing of harmonic frequency or harmonic number the efficiency gradually fell down as a result of lowering of the initial harmonic levels.

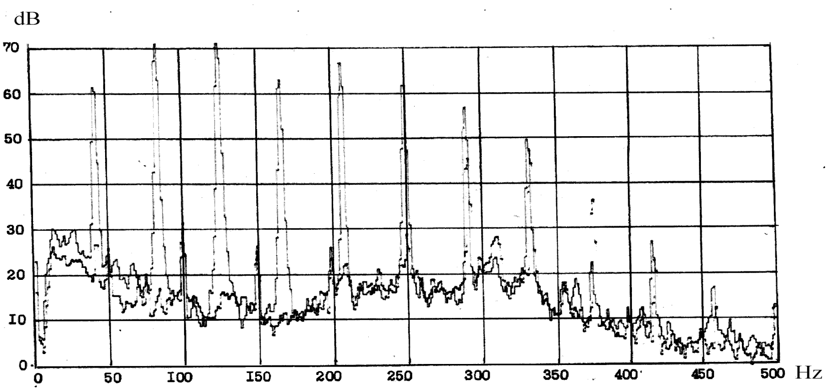

Fig. 3.

The adaptive control algorithm – the operator ***W*** in the equation (2) ensuring the given efficiency of noise reduction in rather wide continuous frequency range was worked out for the mode of narrow-band noise reduction [2,7]. The doubtless advantage of the system with the developed control algorithm consists in the absence of the basic receivers. The system of such type is not optimum and similar to an astatic system of automatic error-closing control. When reducing of narrow-band noise excited by several asynchronous mechanisms with various slipping at rotation frequency ~50 Hz, the efficiency is ~20 dB. The frequency range of effective noise reduction is ~6-8 Hz, that is too much wider than the spectrum of narrow-band noise. Note that in this mode it is possible to change the frequency band pass width and central frequency of the band of effective noise reduction by giving the appropriate algorithm parameters.

The given results show, that the multimode adaptive system is considered to be an effective, and flexible means of reduction of low-frequency noise rose by the rotary type equipment. Being supplied by the appropriate electro-acoustic converters – a vibrator and accelerometers instead of a loudspeaker and microphones the system considered above can also be used for vibration reduction.

The adaptive one-channel system of noise reduction can be also generalized to the multi-channel system of noise and vibration reduction.

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