Algorithms and Intelligent Technologies for Improving the Adequacy of Monitoring and Diagnostics of the Beginning of the Latent Period and Dynamics of Development of Accidents on the Rolling Stock and Railroad Tracks

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***Abstract*—Control and diagnostic systems currently used in rolling stock diagnose malfunctions in wheel-and-motor units, bearing defects, wheel-and-motor units, bearing misalignments, mounting defects, imbalance of rotating parts, gearbox defects. They also diagnose leaks in the feed and brake lines, break valve malfunctions, brake cylinder malfunctions, compressor malfunctions. In this case, parameters of vibration, pressure, force, current, voltage, resistance, pulses, time intervals are used as diagnostic indicators. The control results are primarily reflected on the driver's monitor. However, these systems do not detect the beginning of the latent period of the onset of a malfunction, which usually precedes an accident. In addition, these systems provide no information on the dynamics of its development. Therefore, the result of control is sometimes belated and does not allow taking appropriate measures in time. In addition, modern geometry cars, flaw detector cars and other track test cars are used to control the technical condition of the railroad track, which provide reliable control of the technical condition of the railroad track at "certain intervals of time". At the same time, in real life, due to the impact of various factors, such as seismic processes, certain malfunctions may occur even a day after control. Therefore, it is of great practical importance to create technologies and technical means of "continuous" control of the technical condition of the railroad track, railroad bridges, tunnels and other infrastructure elements. In this paper, the authors propose intelligent technologies and technical tools that make it possible to control the beginning of the latent period of the origin of malfunctions and the dynamics of the development of changes in the technical condition of the track. They are convenient for implementation in the form of a "black box" and can be easily installed in one of the cars of the rolling stock.**

Keywords*—transport corridor, railroad tracks, rolling stock, East-West transport corridor, diagnostics, accident

I. Introduction

The main condition for ensuring the safety of train movement in railway transport is the reliable and fail-safe operation of rolling stock. To ensure the required reliability of the rolling stock, it is necessary to constantly control the technical condition of its running gear. In modern conditions, obtaining reliable information about their technical condition is impossible without technical diagnostics systems. Various diagnostic systems are currently used to assess the technical condition of the running gear of rolling stock in motion (based on the principle of their use: stationary, airborne, portable, incorporated directly into the controlled object, etc.). The main goal of technical diagnostics is to determine the type and location of defects. Vibration parameters, pressure, force, current, voltage, resistance, pulses, time intervals, etc. are used as diagnostic indicators. Receiving the information about deviations from the nominal values of the controlled parameters (temperature, vibration, noise, etc.) during movement, the driver of a high-speed passenger train informs the dispatcher, who, in turn, informs the relevant departments.

Let us consider the example of axleboxes of wheelsets, one of the critical units of the running gear of the rolling stock, which mainly consist of roller bearings. Currently, to monitor the technical condition of the axlebox bearings, automatic temperature and noise control systems with built-in sensors in the axleboxes are used. They make it possible to monitor the parameters of the technical condition of the axleboxes and generate information about deviations from the nominal readings. And this will make it possible to take timely measures and thereby prevent the development of emergency situations. For instance, the system for passenger cars allows obtaining information about the temperature of the axlebox unit using sensors built into the axlebox housing of the wheelset bearings. The control system ensures the processing and storage of the received information, as well as alerts to dangerous heating of the bearings. However, this system monitors only the unit temperature and notifies the train personnel of its value. This does not always allow controlling the beginning and dynamics of the development of bearing damage. As a result, there are challenges and difficulties in eliminating it. In this regard, the development of more effective alternative options for solving the problems of controlling the onset of the initiation and dynamics of the development of malfunctions on the running gear of the rolling stock is required.

In addition to controlling the operation of the rolling stock, it is also important to control the technical condition of the railroad track. At present, this work is carried out by modern geometry cars, flaw detector cars and other track test cars at “certain intervals of time”. Their number is limited and therefore, at present, "continuous control" of all hauls of the track practically impossible. At the same time, in real life, due to the impact of various factors, such as torrential rains, hurricane winds, seismic processes and so on, certain changes that can cause catastrophic accidents may take place even a day after control. In this regard, it is of great practical importance to create technologies and technical means of "continuous" control of the technical condition of the railroad track. It is also important to carry out continuous control of the technical condition of railroad bridges, tunnels and other infrastructure elements.

The studies carried out have shown that to solve this problem, first of all, it is necessary to create algorithms and technologies that allow ensuring the adequacy of the operation of systems for the control and diagnostics of the railroad tracks. Analysis has shown that one of the possible options for “continuous” monitoring the beginning of changes in the technical condition of the track can be implemented with intelligent tools, which allow one, by analyzing the useful signal and the noise from the soil vibrations caused by the rolling stock, to form informative attributes for identifying the technical condition of the track. Due to the simplicity and the reliability of implementation of the proposed technical tools, they can be easily installed in the form of a “black box” in one of the cars of all rolling stocks, providing control of the beginning of changes in the technical condition of the track during their movement in all hauls.

II. Problem Statement. The Importance of Ensuring the Adequacy of Control of the Beginning of the Latent Period and the Dynamics of the Development of Accidents in Rail Transport

It is known that under the normal state of operation of the rolling stock, in the signals received at the outputs of the corresponding sensors, the conditions of stationarity, normality of the distribution law and the absence of correlation between $R_{X\varepsilon}(\mu)$, $r_{X\varepsilon}$, the useful signal $X(t)$ and the noise $\varepsilon(t)$ are satisfied, i.e.,

$$\begin{cases} g(t) = X(t) + \varepsilon_1(t) \\ R_{X\varepsilon}(\mu = 0) \approx 0, \; r_{X\varepsilon} \approx 0 \end{cases} \quad (1)$$

It is also known that as a result of the initiation of malfunctions preceding the accidents, the noise $\varepsilon_2(t)$ is formed, which has a correlation with the useful signal $X(t)$. In this case, a correlation arises between the useful signal $X(t)$ and the sum noise $\varepsilon_1(t) + \varepsilon_2(t)$, i.e.,

$$\begin{cases} g(t) = X(t) + \varepsilon_{11}(t) + \varepsilon_{21}(t) \\ R_{X\varepsilon}(\mu = 0) \neq 0, \; r_{X\varepsilon} \neq 0 \end{cases} \quad (2)$$

In the first case, the estimate of the variance of the noisy signal $g(t)$ is determined from the expression

$$D_{gg} = M[g(t)g(t)] = M\big[\big(X(t) + \varepsilon_1(t)\big)\big(X(t) + \varepsilon_1(t)\big)\big] = \\ = M[X(t)X(t) + \varepsilon_1(t)\varepsilon_1(t)] = D_{XX}(0) + D_\varepsilon, \quad (3)$$

where the estimate of the variance of the noise is determined from the formula

$$M[\varepsilon_1(t)\varepsilon_1(t)] = M[\varepsilon(t)\varepsilon(t)] = D_\varepsilon. \quad (4)$$

In the second case, the estimate of the variance of the sum signal $g(t)$ is determined from the expression

$$D_{gg} = M\{[X(t) + \varepsilon_1(t) + \varepsilon_2(t)][X(t) + \varepsilon_1(t) + \varepsilon_2(t)]\} = \\ = M[X(t)X(t) + \varepsilon_2(t)X(t) + X(t)\varepsilon_2(t) + \varepsilon_1(t)\varepsilon_1(t) \\ + \varepsilon_2(t)\varepsilon_2(t)] = \\ = R_{XX}(t) + 2R_{X\varepsilon_2}(t) + D_{\varepsilon_1\varepsilon_1} + D_{\varepsilon_2\varepsilon_2}, \quad (5)$$

where the estimate of the variance of the sum noise is determined from the expression

$$D_\varepsilon = M[\varepsilon_2(t)X(t) + X(t)\varepsilon_2(t) + \varepsilon_1(t)\varepsilon_1(t) + \varepsilon_2(t)\varepsilon_2(t)] = \\ = 2R_{X\varepsilon_2}(0) + D_{\varepsilon_1\varepsilon_1} + D_{\varepsilon_2\varepsilon_2} = 2R_{X\varepsilon} + D_{\varepsilon\varepsilon}\,0. \quad (6)$$

As can be seen from expressions (4) and (6), the estimates of the result of the analysis of noisy signals in the normal state of objects coincide. However, they differ significantly at the beginning of the latent period of accidents. Because of this, the adequacy of the results of control and diagnostics at the beginning of the latent period of accidents in rolling stock using traditional technologies in most cases is not ensured. Control of the technical condition of the railrod tracks is carried out by determining the time interval by means of track test cars. Their continuous control is also a relevant and important problem. In view of the above, the detection of the occurrence of malfunctions by the rail transport control system turns out to be delayed. Occasionally, for this reason, accidents with undesirable results occur. Therefore, to improve the safety of rolling stock operation and to ensure the quality of control of railroad tracks, bridges and tunnels, we consider options for creating a technology that will improve the adequacy of the results of control in the latent period of an emergency state. The issue of controlling the dynamics of the development of accidents is also discussed in the paper.

III. Possibilities of Ensuring the Adequacy of the Results of Correlation and Spectral Control of the Beginning of Malfunctions in Rail Transport Using the Technology of Equivalent Noises

As mentioned above, according to expressions (1)-(6), the occurrence of malfunctions manifests itself in the form of noises on the noisy signals $g(t)$ received on the corresponding sensors, i.e.,

$$g(t) = X(t) + \varepsilon_1(t) + \varepsilon_2(t) \quad (7)$$

where $X(t)$ is the useful signal, $\varepsilon_1(t)$ is the noise caused by external factors, $\varepsilon_2(t)$ is the noise caused by the initiation of defects that precede malfunctions. As mentioned above for the noisy signal $g(t) = X(t) + \varepsilon(t)$, if the condition of the absence of a correlation between the useful signal and the noise is satisfied, then the analysis results obtained using traditional technologies can be considered adequate. However, when the noisy signal $g(t)$ has form (7), the following expressions take place:

$$g(t) = X(t) + \varepsilon_1(t) + \varepsilon_2(t)$$
$$\varepsilon(t) = \varepsilon_1(t) + \varepsilon_2(t)$$
$$R_{XX}(\mu)=\mathrm{M}[X(t)X(t+\tau)] \neq R_{gg}(\mu)=\mathrm{M}[g(t)g(t+\tau)]$$
$$D_\varepsilon = R_{\varepsilon\varepsilon}(\mu=0)=\mathrm{M}[\varepsilon(t)\varepsilon(t)]$$
$$R_{X\varepsilon}(0)=\mathrm{M}\,[X(t)\varepsilon(t)]$$
$$r_{gg}(\tau) \neq r_{XX}(\tau)$$
$$a_{n_X}=\mathrm{M}[X_n \sin n\omega t] \neq a_{n_g}=\mathrm{M}[g_n \sin n\omega t]$$
$$b_{n_X}=\mathrm{M}[X_n \cos n\omega t] \neq b_{n_g}=\mathrm{M}[g_n \cos n\omega t]$$

where $R_{gg}(\mu)$, $R_{XX}(\mu)$ are the estimates of the correlation functions of the useful signal $X(t)$ and the noisy signal $g(t)$, $R_{X\varepsilon}(0)$ is the estimate of the cross-correlation function between the useful signal $X(t)$ and the noise $\varepsilon(t)$, $r_{gg}(\tau)$, $r_{XX}(\tau)$ are the normalized correlation functions of the noisy signal $g(t)$ and the useful signal$X(t)$, a_{n_X}, b_{n_X}, a_{n_g}, b_{n_g} are the estimates of the spectral characteristics of the useful signal$X(t)$, the noisy signal $g(t)$ and the noise$\varepsilon(t)$.

It is obvious from these expressions that when the correlation between the useful signal $X(t)$ and the noise $\varepsilon(t)$ differs from zero, the adequacy of the results of the analysis of noisy signals using traditional technologies will be unsatisfactory. The studies have shown that in order to eliminate the difficulty of ensuring the adequacy of the analysis of noisy signals, it is first of all necessary to create a technology for determining the estimates of the correlation characteristics of the noise $\varepsilon(t)$ of noisy signals [7-9]. For this purpose, technologies are proposed for determining the estimates of the noise variance D_ε and the cross-correlation functions between the useful signal and the noise $R_{X\varepsilon}(\mu)$.

These studies [7-9] have shown that in order to solve the problem of ensuring the adequacy of the results of control and diagnostics, it is necessary to create a technology for forming equivalent noises, in whose estimates obtained as a result of their analysis would coincide with the results of the analysis of the noises of noisy signals. In this case, by analyzing the equivalent noises, it is necessary to ensure that the obtained estimates are equivalent to the estimates of noisy signals.

Taking into account the above, various options for forming equivalent noises were considered. All of them have been tested by numerous computational experiments. Through an analysis of the proposed options, it has been found that there are few practically feasible options. The most expedient of them was replacing the non-measurable noise samples $\varepsilon(i\Delta t)$ with their approximate equivalent values $\varepsilon^e(i\Delta t)$,

$$\varepsilon(i\Delta t) \approx \varepsilon^e(i\Delta t) = \operatorname{sgn} \varepsilon'(i\Delta t) \times \sqrt{|g^2(i\Delta t) + g(i\Delta t)g((i+2)\Delta t) - 2g(i\Delta t)g((i+1)\Delta t)|} = \operatorname{sgn} \varepsilon'(i\Delta t)\sqrt{|\varepsilon'(i\Delta t)|}. \quad (8)$$

Here, assuming that the following expression is true

$$D_\varepsilon = \frac{1}{N}\sum_{i=1}^{N} \varepsilon^2(i\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} \varepsilon^{e2}(i\Delta t) = \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)[g(i\Delta t) + g((i+2)\Delta t) - 2g((i+1)\Delta t)], \quad (9)$$

the formula for calculating the mean value $\bar{\varepsilon}(i\Delta t)$ of samples of the noise $\varepsilon(i\Delta t)$ can be reduced to the calculation of the mean value of the equivalent samples of the noise $\varepsilon^e(i\Delta t)$, i.e.:

$$\bar{\varepsilon}(i\Delta t) \approx \overline{\varepsilon^e}(i\Delta t) = \frac{1}{N}\sum_{i=1}^{N} \varepsilon^e(i\Delta t), \quad (10)$$

$$\frac{1}{N}\sum_{i=1}^{N} \varepsilon^e(i\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} \varepsilon(i\Delta t). \quad (11)$$

The possibility of forming equivalent noises allows us to determine equivalent samples of the useful signal $X^e(i\Delta t)$ and the estimates of $R_{XX}(\mu)$, $R_{X\varepsilon}(\mu)$ and other characteristics of the noisy signal, i.e.,

$$X^e(i\Delta t) = g(i\Delta t) - \varepsilon^e(i\Delta t) \quad (12)$$

$$R^e_{XX}(\mu) \approx R^e{}_{X^eX^e}(\mu) == \frac{1}{N}\sum_{i=1}^{N} X^e(i\Delta t)X^e\big((i+\mu)\Delta t\big) \approx \frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)X\big((i+\mu)\Delta t\big) \quad (13)$$

$$R^e_{X\varepsilon}(\mu) \approx \frac{1}{N}\sum_{i=1}^{N} X^e(i\Delta t)\varepsilon^e\big((i+\mu)\Delta t\big) \approx \frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)\varepsilon\big((i+\mu)\Delta t\big) \quad (14)$$

where $X^e(i\Delta t)$ is the equivalent sample of the useful signal $X(t)$, $\varepsilon^e(i\Delta t)$ is the equivalent sample of the noise $\varepsilon(t)$.

Thus, using (8)-(14) makes it possible to isolate from the noisy signal an equivalent useful signal $X^e(i\Delta t)$ and an equivalent noise $\varepsilon^e(i\Delta t)$, for which the estimates of $R^e_{XX}(\mu)$ and $R^e_{X\varepsilon}(\mu)$ coincide with the estimates of the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$. This allows improving the adequacy of the malfunction control.

IV. Algorithms for Improving the Adequacy of Control Results Using Traditional Technologies

When considering possible options for improving the adequacy of results of control and diagnostics in rail transport, it becomes obvious that it is first and foremost necessary to create algorithms and technologies for eliminating errors in traditional technologies for analyzing noisy signals.

For this purpose, we will consider the possibility of determining the main errors of traditional technologies of correlation and spectral analysis:

$$R_{gg}(\mu) = \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)\, g((i+\mu)\Delta t) = \frac{1}{N}\sum_{i=1}^{N}(X(i\Delta t) + \varepsilon(i\Delta t))(X(i+\mu)\Delta t) + \varepsilon((i+\mu)\Delta t)) = \frac{1}{N}\sum_{i=1}^{N}[X(i\Delta t)\,X\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)X\big((i+\mu)\Delta t\big) + X(i\Delta t)\varepsilon\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)\varepsilon((i+\mu)\Delta t) = R_{XX}(\mu) + R_{\varepsilon X}(\mu) + R_{X\varepsilon}(\mu) + R_{\varepsilon\varepsilon}(\mu)$$

Therefore, the error $\lambda_{gg}(\mu)$ of traditional technologies can be determined from the formula

$$\lambda_{gg}(\mu) \approx \frac{1}{N}\sum_{i=1}^{N}\Big[X(i\Delta t)\varepsilon\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)X\big((i+\mu)\Delta t\big) + \varepsilon(i\Delta t)\varepsilon((i+\mu)\Delta t)\Big]$$

which show that to eliminate it, it is necessary to determine the estimates $R_{X\varepsilon}(0)$, $R_{X\varepsilon}(\mu)$ and $R_{\varepsilon\varepsilon}(0)$, i.e.

$$\lambda_{gg}(\mu) \approx \begin{cases} 2R_{X\varepsilon}(0) + R_{\varepsilon\varepsilon}(0) & \text{when} \quad \mu = 0 \\ 2R_{X\varepsilon}(\mu) & \text{when} \quad \mu \neq 0 \end{cases}$$

It is obvious that the estimates of $R_{XX}(\mu)$ an be determined from the expression

$$R_{XX}(\mu) \approx \begin{cases} R_{gg}(0) - [2R^{e}_{X\varepsilon}(0) + R^{e}_{\varepsilon\varepsilon}(0)] & \text{when} \quad \mu = 0 \\ R_{gg}(\mu) - 2R^{e}_{X\varepsilon}(\mu) & \text{when} \quad \mu \neq 0 \end{cases} \tag{15}$$

The estimates a_{n_X} and b_{n_X}, i.e., spectral characteristics can also be determined from the expressions

$$\begin{cases} a_{n_X} = \dfrac{2}{T}\displaystyle\int_0^T [X(t) + \varepsilon(t)] \cos n\omega t \, dt = \dfrac{2}{T}\displaystyle\int_0^T [X(t)\cos n\omega t + \varepsilon(t)\cos n\omega t] \, dt \\ b_{n_X} = \dfrac{2}{T}\displaystyle\int_0^T [X(t) + \varepsilon(t)] \sin n\omega t \, dt = \dfrac{2}{T}\displaystyle\int_0^T [X(t)\sin n\omega t + \varepsilon(t)\sin n\omega t] \, dt \end{cases}$$

$$\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t)$$

which can be calculated after determining the estimates $\lambda_{a_{n_X}}$ and $\lambda_{b_{n_X}}$, from the expressions

$$\begin{cases} a_{n_g} = \frac{2}{N}\sum_{i=1}^{N} g(i\Delta t)\cos n\omega\,(i\Delta t) - \lambda_{a_n} = a_{n_X} \\ b_{n_g} = \frac{2}{N}\sum_{i=1}^{N} g(i\Delta t)\sin n\omega\,(i\Delta t) - \lambda_{b_n} = b_{n_X} \end{cases} \tag{16}$$

$$\begin{cases} \lambda_{a_n} = \displaystyle\sum_{i=1}^{N^+}\int_{t_1}^{t_{i+1}} \varepsilon(t)\cos n\omega t\, dt - \sum_{i=1}^{N-}\int_{t_1}^{t_{i+1}} \varepsilon(t)\cos n\omega t\, dt \\ \lambda_{b_n} = \displaystyle\sum_{i=1}^{N^+}\int_{t_1}^{t_{i+1}} \varepsilon(t)\sin n\omega t\, dt - \sum_{i=1}^{N-}\int_{t_1}^{t_{i+1}} \varepsilon(t)\sin n\omega t\, dt \end{cases}$$

$$\lambda_{a_n} = \left[\frac{N^+_{a_n} - N^-_{a_n}}{N}\bar{\lambda}_a(i\Delta t)\right], \quad \lambda_{b_n} = \left[\frac{N^+_{b_n} - N^-_{b_n}}{N}\bar{\lambda}_b(i\Delta t)\right]$$

$$\bar{\lambda}_{a_n}(i\Delta t) = \overline{|\sqrt{D_\varepsilon}\cos n\omega(\imath\Delta t)\,|}, \quad \bar{\lambda}_{b_n}(i\Delta t) = \overline{|\sqrt{D_\varepsilon}\sin n\omega(\imath\Delta t)\,|}$$

Thus, determining the estimates of the correlation functions $R_{XX}(\mu)$ and the spectral characteristics a_{n_X}, b_{n_X} of useful signals according to formulas (15), (16), it is possible to eliminate the errors of traditional technologies.

This opens up a possibility to improve the adequacy of solving a wide range of control and identification problems for both rolling stock and railroad tracks.

V. Correlation Technology for Noise Control of the Beginning and Dynamics of Development of the Latent Period of Accidents in Rail Transport

It is shown in [1] that at the beginning of the latent period of the initiation of accidents as a result of the appearance of the noise $\varepsilon_2(i\Delta t)$, the estimate of the cross-correlation function between the sum noise $\varepsilon_2(i\Delta t)$ and the useful signal $X(i\Delta t)$ differs from zero. At the same time, in a stable emergency state, this estimate does not change. However, as the defect develops, this estimate increases. This makes it possible to control the dynamics of the development of accidents. However, by increasing or decreasing the value of the estimates of the noise variance, it is impossible to control the dynamics of the development of accidents. As numerous experiments show, the dynamics of the development of accidents leads both to an increase in the variance of the noise $\varepsilon_2(i\Delta t)$, which leads to an increase in the correlation between the useful signal and the noise. As a result, in the presence of the dynamics of the development of a malfunction, a correlation first arises between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. Then the further development of dynamics leads to the appearance of a correlation between $X(i\Delta t)$ and $\varepsilon(i+2)\Delta t$, then between $X(i\Delta t)$ and $\varepsilon(i+3)\Delta t$, etc. Therefore, to control the dynamics of the development of accidents, it is necessary to calculate the estimates corresponding to the cross-correlation function between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. In [1], the possibility of calculating the estimate of $R_{X\varepsilon}(\Delta t)$ is considered and it is shown that if there is a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at m different time shifts $\mu = m\Delta t$, $m = 1, 2, 3, \ldots$, it is advisable to use a generalized expression in the form

$$R_{X\varepsilon}(m\Delta t) \approx \frac{1}{2N}\sum_{i=1}^{N}\Big[\, g(i\Delta t)g\Big(\big(i + (\mathrm{m}+1)\big)\Delta t\Big) - 2g(i\Delta t)g\Big(\big(i + (\mathrm{m}+1)\big)\Delta t\Big) + g(i\Delta t)g\Big(\big(i + (\mathrm{m}+2)\big)\Delta t\Big)\Big].$$

An experimental analysis of noisy signals received at various technical facilities [1-12] showed that, depending on the degree of dynamics of the development of accidents at these facilities, a correlation appears between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ first at $\mu = 1\Delta t$, then at $\mu = 2\Delta t$, $\mu = 3\Delta t$, then at $\mu = 4\Delta t, 5\Delta t, 6\Delta t$, etc. Moreover, the values of these estimates reflect the dynamics of the development of accidents over time. Due to this, the generalized expression for calculating the estimates $R_{X\varepsilon}(\mu = 1\Delta t), R_{X\varepsilon}(\mu = 2\Delta t), R_{X\varepsilon}(\mu = 3\Delta t), \ldots, R_{X\varepsilon}(\mu = m\Delta t)$ makes it possible to control and diagnose not only the beginning, but also the dynamics of the development of rolling stock malfunctions.

As shown above, at the beginning of the latent period of malfunctions, the error $\varepsilon_2(i\Delta t)$ appeares as a result of the initiation of various defects. At the same time, in essence, the dynamics of the development of accidents, despite the indirect influence on the value of the estimate of the noise variance, uniquely manifests itself only in the estimates of the cross-correlation functions between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at different time shifts. Therefore, as indicated above, to control the dynamics of the development of accidents, it is advisable to use the estimate of $R_{X\varepsilon}(m)$. However, quite often, to control the onset and dynamics of the latent period of accidents, it is possible to use easily implementable algorithms that make it possible to significantly simplify the solution of this problem. From this point of view, it is advisable to use estimates of relay correlation functions, which can be calculated from the formula

$$R^*_{X\varepsilon}(\mu) = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } g(i\Delta t)\varepsilon^2(i\Delta t) = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } X(i\Delta t)\varepsilon^2(i\Delta t).$$

However, to use this formula, it is necessary to determine the samples of the noise $\varepsilon(i\Delta t)$, which cannot be measured directly.

The following estimate can be used as informative attributes:

$$R^*_{X\varepsilon}(\mu) = \frac{1}{N}\sum_{i=1}^{N} \text{sgn } g(i\Delta t)\big[g(i\Delta t)g(i\Delta t) - 2g(i\Delta t)g\big((i+1)\Delta t\big) + g(i\Delta t)g\big((i+2)\Delta t\big)\big]=\frac{1}{N}\sum_{i=1}^{N} \text{sgn } g(i\Delta t)\varepsilon^2(i\Delta t)$$

$$\varepsilon^2(i\Delta t) = g(i\Delta t)\big[g(i\Delta t)g(i\Delta t) - 2g(i\Delta t)g\big((i+1)\Delta t\big) + g(i\Delta t)g\big((i+2)\Delta t\big)\big]$$

It is also advisable to use for these purposes simple options for the approximate calculation of estimates of the relay cross-correlation function $R^*_{X\varepsilon}(\mu)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ at various time shifts $m\Delta t$:

$$R^*_{X\varepsilon}(m\Delta t) \approx \frac{1}{2N}\sum_{i=1}^{N}\Big[\text{sgn } g(i\Delta t)g\big((i+m)\Delta t\big) - 2\text{ sgn } g(i\Delta t)g\Big(\big(i+(m+1)\big)\Delta t\Big) + \text{sgn } g(i\Delta t)g\Big(\big(i+(m+2)\big)\Delta t\Big)\Big].$$

When this formula is used, in the case of the presence of dynamics of the malfunction development, the obtained estimate will change at different time shifts [1]. At the same time, by determining the estimate of the relay cross-correlation function $R^*_{X\varepsilon}(\mu\Delta t)$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ at different $\mu\Delta t$, it is possible to control the dynamics of the development of the malfunction.

For instance, at $\mu = 1\Delta t$, the formula for calculating the estimate $R^*_{X\varepsilon}(\mu = 1\Delta t)$ will have the form

$$R^*_{X\varepsilon}(\mu = 1\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N}[\text{sgn}g(i\Delta t)g(i+1)\Delta t - 2\text{ sgn } g(i\Delta t)g(i+2)\Delta t + \text{sgn } g(i\Delta t)g(i+3)\Delta t].$$

At $\mu = 2\Delta t$, the formula for calculating the estimate $R^*_{X\varepsilon}(\mu = 2\Delta t)$ will have the form

$$R^*_{X\varepsilon}(\mu = 2\Delta) \approx \frac{1}{N}\sum_{i=1}^{N}[\text{sgn } g(i\Delta t)g(i+2)\Delta t - \text{sgn } g(i\Delta t)g(i+3)\Delta t + \text{sgn } g(i\Delta t)g(i+4)\Delta t].$$

It is obvious that the estimates $R^*_{X\varepsilon}(\mu = 3\Delta t), R^*_{X\varepsilon}(\mu = 4\Delta t)$, ..., can be calculated in a similar manner.

It is clear that in the absence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the estimate of the cross-correlation function $R_{X\varepsilon}(\mu = 0)$ between the useful signal and the noise will be close to zero. It is also obvious that at the initiation of various defects preceding accidents at the facility, as a result of the appearance of the noise $\varepsilon_2(i\Delta t)$ ($\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t)$), the value of the estimate of the relay cross-correlation correlation function due to the presence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ will increase sharply. A distinctive feature of this algorithm is that at the initiation of various malfunctions, when a correlation occurs between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the differences in the estimates $R^*_{X\varepsilon}(1\Delta t)$, $R^*_{X\varepsilon}(2\Delta t)$, $R^*_{X\varepsilon}(3\Delta t)$ unambiguously reflect the dynamics of the development of accidents, which makes it possible to provide reliable information on the dynamics of the malfunction development.

Similarly, using the corresponding formulas for other Noise characteristics of the noisy signals $g(i\Delta t)$, [1, 9-12], it is possible to increase the reliability and adequacy of control of the beginning of the latent period and the dynamics of the development of malfunctions preceding accidents in rail transport.

$$R^*_{1X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'(i\Delta t)g'(i\Delta t) - 2g'(i\Delta t)g'\big((i+1)\Delta t\big) + g'(i\Delta t)\, g'\big((i+2)\Delta t\big)$$

$$R^*_{2X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'(i\Delta t)g(i\Delta t) - 2g'(i\Delta t)g\big((i+1)\Delta t\big) + g'(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R^*_{3X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g^2(i\Delta t)g(i\Delta t) - 2g^2(i\Delta t)g\big((i+1)\Delta t\big) + g^2(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R^*_{4X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} g'^2(i\Delta t)g'(i\Delta t) - 2g'^2(i\Delta t)g'\big((i+1)\Delta t\big) + g'^2(i\Delta t)\, g'\big((i+2)\Delta t\big)$$

$$R^*_{5X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} sgn\ g(i\Delta t)g(i\Delta t) - 2sgn\ g(i\Delta t)g\big((i+1)\Delta t\big) + sgn\ g(i\Delta t)g\big((i+2)\Delta t\big)$$

$$R^*_{6X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} sgn\ g'(i\Delta t)g'(i\Delta t) - 2sgn\ g'(i\Delta t)g'\big((i+1)\Delta t\big) + sgn\ g'(i\Delta t)\, g'\big((i+2)\Delta t\big)$$

where $g(i\Delta t)$ is the centered noisy signal, $g'(i\Delta t)$ is the non-centered noisy signal, $R_{X\varepsilon}(\mu\Delta t)$ is the cross-correlation function between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $\mu\Delta t$ is the time shift between the samples of the useful signal $X((i+\mu)\Delta t)$ and the noise $\varepsilon(i\Delta t)$; $g((i+\mu)\Delta t)$ is the $(i+\mu)$-th sample of the centered noisy signal; $g'(i\Delta t)$ is the sample of the non-centered noisy signal; N us the number of samples.

VI. Technology for Determining the Dynamics of the Malfunction Development by Changing the Shape of the Curve of the Distribution Law of the Noise of Noisy Signals

The studies carried out have shown that to control the dynamics of the malfunction development, it is possible to use the approximate values of the estimates of the curve of the distribution law of the noise $\varepsilon(i\Delta t)$. For this purpose, first of all, the equivalent samples of the noise $\varepsilon^e(i\Delta t)$ are determined.

Numerous experiments have shown that despite the possible deviations of the approximate values of the samples of $\varepsilon^e(i\Delta t)$ from their true values $\varepsilon(i\Delta t)$ by $\varepsilon^e(i\Delta t) - \varepsilon(i\Delta t)$, the following equality holds between their estimates

$$P\left\{\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e2}(i\Delta t) - \frac{1}{N}\sum_{i=1}^{N}\varepsilon^2(i\Delta t) \approx 0\right\} = 1,$$

$$P\left\{\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e}(i\Delta t)-\frac{1}{N}\sum_{i=1}^{N}\varepsilon(i\Delta t)\approx 0\right\}=1,$$

where P is the probability sign. This equality shows that by constructing the distribution law of the equivalent noise $\varepsilon^{e}(i\Delta t)$, one can obtain results identical to the results of the analysis of the noise $\varepsilon(i\Delta t)$, i.e, the possibility of calculating the approximate values of the equivalent samples of the noise $\varepsilon^{e}(i\Delta t)$ makes it possible to construct the distribution law of the noise $\varepsilon(i\Delta t)$. It is known that the coordinates of the curve of the distribution law of the noise are determined for this purpose. Therefore, $W(\varepsilon)$ is determined corresponding values of its curve from N samples of the noise $\varepsilon(i\Delta t)$ for the time $T=N\Delta t$. For this purpose, the approximate value of the samples of the equivalent noise $\varepsilon_{2}^{a}(\mathrm{i}\Delta\mathrm{t})$. is used. For this, by the number of samples $N_1, N_2, \dots, N_m$ of $\varepsilon^{e}(i\Delta t)$, given in the range from 0 to $\varepsilon_{\max}$ through equal intervals Δt, it is possible to construct the distribution law $W(\varepsilon)$.

Note that, in a similar way, by reading the square of the noise $\varepsilon^{2}(i\Delta t)$, it is possible to determine the $N_1, N_2, \dots, N_m$ coordinates of the distribution law curve for $\varepsilon^{2}(i\Delta t)$. Obviously, this curve will be identical in shape to the curve of the distribution law of the noise $\varepsilon(i\Delta t)$. $\varepsilon^{2}(i\Delta t)$ here is determined from formula (8), (9).

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The construction of the distribution law for the equivalent noise $\varepsilon^{e}(i\Delta t)$ is carried out as follows. The minimum value ε_{min} is set, and if the condition $[\varepsilon_{min}+j\Delta x]\le\varepsilon(i\Delta t)\le[\varepsilon_{min}+(j+1)\Delta x]$ is satisfied, their number is determined. Then this value is increased by Δx for all samples of the approximate values of the noise $\varepsilon^{e}(i\Delta t)$, and this process is repeated. The construction of the curve of the distribution law for $\varepsilon^{e2}(i\Delta t)$ is carried out in a similar way.

Therefore, the construction of the distribution law $W(\varepsilon)$ for both options is carried out in a similar way. Moreover, in both cases, for the values $j=0, j=1, j=2, \dots, j=m$, we successively determine the number of samples $\mathrm{N}_0, \mathrm{N}_1, \mathrm{N}_2, \dots, \mathrm{N}_\mathrm{m}$, at which the specified conditions are met. It is clear that using the results obtained it is possible to construct a curve of the distribution law both for the case $W[\varepsilon^{e}(i\Delta t)]$ and for the case $W[\varepsilon^{2}(i\Delta t)]$. As the number of samples N increases, these curves tend to the distribution law of the noise itself, i.e., $W(\varepsilon)$. In the presence of dynamics of the malfunction development of the shape of both curves of the distribution laws of both $W[\varepsilon^{e}(i\Delta t)]$ and $W[\varepsilon^{2}(i\Delta t)]$ change after a certain time interval $\Delta\tau$. The difference between the samples of the distribution law curves here will depend on the dynamics of the malfunction development.

In conclusion, it should be noted that the resources of modern personal computers make it quite easy to implement the above technology in practice.

VII. Spectral Technology for the Noise Signaling of the Beginning of the Latent Period of Accidents in Rail Transport

An analysis of technologies of the possibility of using spectral noise control has shown that early diagnostics of the onset and dynamics of changes in the latent period of malfunctions is very important during the operation of rolling stock. However, the use of the technology of spectral analysis of the noisy signal $g(i\Delta t)$, usually obtained at the output of the sensors, does not provide the adequacy of the diagnostic results. Therefore, for this purpose, it is advisable to use the estimates of the spectral characteristics of the noise $\varepsilon(i\Delta t)$ of noisy signals $g(i\Delta t)$ as informative attributes, according to the expressions

$$a_{n_\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon\,(i\Delta t)\cos n\omega(i\Delta t)$$

$$b_{n_\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon(i\Delta t)\sin n\omega(i\Delta t)$$

However, these algorithms cannot be implemented in practice, since it is impossible to determine the samples of the noise $\varepsilon(i\Delta t)$. At the same time, as already shown above, it is possible to determine the samples of the equivalent noise $\varepsilon(i\Delta t)$ from expressions (8), (9).

$$a_{n\varepsilon}^{*}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e2}\,(i\Delta t)\cos n\omega(i\Delta t)$$

$$b_{n\varepsilon}^{*}=\frac{1}{N}\sum_{i=1}^{N}\varepsilon^{e2}(i\Delta t)\sin n\omega(i\Delta t)$$

where

$$\varepsilon^{e2}(i\Delta t)=g(i\Delta t)\big[g(i\Delta t)g(i\Delta t)-2g(i\Delta t)g\big((i+1)\Delta t\big)+g(i\Delta t)g\big((i+2)\Delta t\big)\big].$$

These studies have also shown that the technology of relay and sign spectral analysis of the noise using expressions can also be used for the signaling of the beginning of the initiation of malfunctions

$$a'_{n\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\operatorname{sgn}\cos n\omega(i\Delta t),$$

$$b'_{n\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\operatorname{sgn}\sin n\omega(i\Delta t),$$

$$a_{n\varepsilon}^{*}=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\cos n\omega(i\Delta t),$$

$$b_{n\varepsilon}^{*}=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\sin n\omega(i\Delta t).$$

The expediency of using the technology of relay and sign spectral analysis of the noise for signaling the beginning of the latent period of accidents is due to the fact that they are easily implemented by hardware.

Besides, to control the dynamics of the development of accidents, it is also advisable to use the technology of relay spectral analysis of the noise according to the expressions:

$$a_{1\varepsilon}^{*}=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\cos n\omega(i\Delta t),$$

$$b_{1\varepsilon}^{*}=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}(i\Delta t)\sin n\omega(i\Delta t),$$

$$a_{2\varepsilon}^{*}=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+1)\Delta t)\cos n\omega(i\Delta t),$$

$$b_{2\varepsilon}^{*}=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+1)\Delta t)\sin n\omega(i\Delta t),$$

....

$$a_{n\varepsilon}^{*}=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+m)\Delta t)\cos n\omega(i\Delta t),$$

$$b_{n\varepsilon}^{*}=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn}\varepsilon^{e2}((i+m)\Delta t)\sin n\omega(i\Delta t).$$

It is obvious that the control of the dynamics of the development of accidents can also be carried out by estimates of the sign spectral characteristics of the noise according to the formulas

$$a_{1\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \mathrm{sgn}\varepsilon^{e^2}(i\Delta t)\mathrm{sgn}\cos n\omega(i\Delta t),$$

$$b_{1\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \mathrm{sgn}\ \varepsilon^{e^2}(i\Delta t)\mathrm{sgn}\sin n\omega(i\Delta t),$$

$$a_{2\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \mathrm{sgn}\ \varepsilon^{e^2}((i+1)\Delta t)\mathrm{sgn}\cos n\omega(i\Delta t),$$

$$b_{2\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \mathrm{sgn}\ \varepsilon^{e^2}((i+1)\Delta t)\mathrm{sgn}\sin n\omega(i\Delta t),$$

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$$a_{n\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \mathrm{sgn}\ \varepsilon^{e^2}((i+m)\Delta t)\mathrm{sgn}\cos n\omega(i\Delta t),$$

$$b_{n\varepsilon}^{**} = \frac{2}{N}\sum_{i=1}^{N} \mathrm{sgn}\ \varepsilon^{e^2}((i+m)\Delta t)\mathrm{sgn}\sin n\omega(i\Delta t).$$

The use of these technologies makes it possible to reliably control the dynamics of the development of accidents at $\mu = 1\Delta t$, $\mu = 2\Delta t$, $\mu = 3\Delta t$, …, $\mu = m\Delta t$. The reliability of the signaling can be ensured by duplicating these estimates with the estimates of the relay correlation functions. Due to the extreme importance of ensuring the fail-safe operation of rolling stock, duplication of the control of the beginning of initiation and dynamics of the malfunction development with several technologies can be considered justified.

VIII. Intelligent System for the Control of the Technical Condition of Railroad Tracks

Fig. 1 shows the block diagram of a system for intelligent Noise monitoring of the technical condition of railroad tracks, consisting of the following modules:

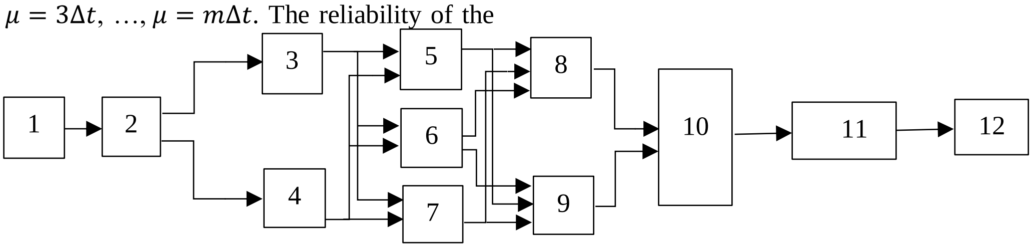

Fig. 1. Intelligent system for the control of the technical condition of railroad tracks

1. Vibration sensor.
2. Module of sampling and formation of centered samples of the noise vibration signals $g(i\Delta t)$.
3. Module of determining the equivalent samples of the useful signal $X(i\Delta t)$.
4. Module of determining the equivalent samples of the noise $\varepsilon^e(i\Delta t)$.
5. Module of determining the equivalent estimates of the correlation functions of the useful signal $R_{X^eX^e}(\mu)$.
6. Module of determining the estimates of the cross-correlation function between the useful vibration signal and the noise $R_{X^e\varepsilon^e}(\mu)$.
7. Module of determining the estimates of the spectral characteristics a_{nX^e}, b_{nX^e}, $a_{n\varepsilon^e}$, $b_{n\varepsilon^e}$ of the useful vibration signal $X(i\Delta t)$ and the noise $\varepsilon^e(i\Delta t)$.
8. Module of formation of current informative attributes consisting of current estimates $R_{X^eX^e}(\mu)$, $R_{X^e\varepsilon^e}(\mu)$, D_{ε^e}, , a_{nX^e}, b_{nX^e}, $a_{n\varepsilon^e}$, $b_{n\varepsilon^e}$, $b_{n_\varepsilon}^{*e}$.
9. Module of formation of the set of reference informative attributes $R_{X^eX^e}^{max}(\mu)$, $R_{X^e\varepsilon^e}^{max}(\mu)$, $D_{\varepsilon^e}^{max}$, $a_{nX^e}^{max}$, $b_{nX^e}^{max}$, $a_{n\varepsilon^e}^{max}$, $b_{n\varepsilon^e}^{max}$.
10. Learning module.
11. Decision-making module.
12. Module of formation of information for signaling and remote transfer.

As can be seen from the block diagram in Fig. 1, the track Noise monitoring system is an inexpensive and fairly simple device, which practically consists of a vibration sensor, a sampling tool and a controller. Therefore, it can be installed in any cars of any train, and at the same time, does not require substantial costs.

The system operates as follows. At the beginning of the operation, the learning process begins and during the movement of the rolling stock in each control cycle, by means of the appropriate modules, the sampled vibration signal $g(i\Delta t)$ is analyzed and the obtained estimates $R_{X^eX^e}(\mu)$, $R_{X^e\varepsilon^e}(\mu)$, D_{ε^e}, , a_{nX^e}, b_{nX^e}, $a_{n\varepsilon^e}$, $b_{n\varepsilon^e}$, $b_{n_\varepsilon}^{*e}$ are saved as informative attributes. In subsequent cycles, current estimates are compared with previous estimates and only those greater than the previous maximum estimates are kept. As a result, the set W_j^e forms after a certain time, which consists of maximum estimates of informative attributes, which are formed in the current cycle. They, i.e. $R_{X^eX^e}^{max}(\mu)$, $R_{X^e\varepsilon^e}^{max}(\mu)$, $D_{\varepsilon^e}^{max}$, $a_{nX^e}^{max}$, $b_{nX^e}^{max}$, $a_{n\varepsilon^e}^{max}$, $b_{n\varepsilon^e}^{max}$ are taken as reference estimates. In the following cycles, this process repeats and similarly forms the subsequent reference set. If the current informative attributes are greater than the maximum reference attributes, then it is assumed that the training for a given haul is completed, and the comparison of current combinations of informative attributes with an element of the set of reference informative attributes begins. If the current attributes are not greater than the reference ones, then the technical condition of the track is considered unchanged. If current informative features are greater than the reference ones, it is assumed that the beginning of the latent period of changes in the technical condition of the track takes place. At the same time, information is formed in Module 12 to signal the advisability of control of the technical condition of a given haul using geometry cars. In the case when no change is detected, it is also possible to form and transmit information about the safety of the track of this haul.

IX. Conclusion

Traditional technologies do not allow extracting diagnostic information sufficient to identify the onset of the latent period of the initiation of defects in the main elements of the running gear of rolling stock. This affects the delays in the detection of the onset of malfunctions, which sometimes leads to unavoidable accidents with undesirable consequences. Consequently, in order to improve the reliability of fail-safe operation and organize timely maintenance of rolling stock, it is necessary to create new, more efficient technologies for analyzing noisy signals, which allow early detection of the beginning of the initiation of malfunctions.

An analysis of malfunctions of the rolling stock undercarriage has shown that when the defects arise, the noisy signals received at the outputs of the sensors contain information about this in the form of noise of a random function. This is due to the fact that noises appear during the initiation of an accident as a result of the imposition of a large number of various dynamic effects arising in the controlled nodes. Therefore, the noises of noisy signals, which are of a chaotic random nature, contain sufficient information about the beginning of a change in the technical condition of the object. For instance, the vibration signals of the axleboxes of wheelsets contain a large number of various noises. They make it difficult to detect the onset of defect initiation when using traditional signal analysis technologies. At the same time, in some cases, it is the noise that are the only carriers of diagnostic information about the beginning of the initiation of a malfunction. Therefore, to control the beginning of the initiation of malfunctions, it is necessary to create technologies that allow calculating informative attributes not only using useful signals, but also noise [7-11]. In order to ensure the control of a defect at the beginning of its initiation, it is necessary first to choose the type and installation locations of the corresponding sensors that ensure the controllability of the object. To analyze both the sum signal $g(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$, it is advisable to apply technologies that allow calculating the corresponding informative attributes.

Due to the extreme importance of ensuring fail-safe operation of the rolling stock, it is advisable to monitor the onset and dynamics of the malfunction development by duplicating several technologies of Noise control and Noise signaling proposed in [7]. The reference set of the estimates of Noise characteristics of noisy signals here will have the form

$$W_j^e = \begin{cases} D_\varepsilon^{max}, R_{X\varepsilon}^{max}(1\Delta t), R_{X\varepsilon}^{max}(2\Delta t), R_{X\varepsilon}^{max}(3\Delta t), \dots, R_{X\varepsilon}^{max}(m\Delta t) \\ R_{X\varepsilon}^{*max}(1\Delta t), R_{X\varepsilon}^{*max}(2\Delta t), R_{X\varepsilon}^{*max}(3\Delta t), \dots, R_{X\varepsilon}^{*max}(m\Delta t) \\ a_{1\varepsilon}^{max}, b_{1\varepsilon}^{max};\ a_{2\varepsilon}^{max}, b_{2\varepsilon}^{max}; a_{3\varepsilon}^{max}, b_{3\varepsilon}^{max}; \dots; a_{n\varepsilon}^{max}, b_{n\varepsilon}^{max} \\ a_{1\varepsilon}^{*max}, b_{1\varepsilon}^{*max};\ a_{2\varepsilon}^{*max}, b_{2\varepsilon}^{*max}; a_{3\varepsilon}^{*max}, b_{3\varepsilon}^{*max}; \dots; a_{n\varepsilon}^{*max}, b_{n\varepsilon}^{*max} \end{cases},$$

which, in combination with the current informative attributes, will form the basis of information support for solving the control problem. As a result, the reliability and adequacy of the results of controlling the onset and dynamics of the development of malfunctions will increase.

To ensure the safety of rail transport, it is important to increase the efficiency of control of the technical condition of the railroad tracks. Modern geometry cars, flaw detector cars and other track test cars are currently used for this purpose, providing reliable control of the technical condition of the railroad track in all hauls at certain intervals. Their number is limited and therefore "continuous control" of all hauls is practically impossible. Therefore, to ensure the safety of the track, they are used on schedule so that the control of each haul takes not less than a certain period of time. It is clear that the smaller this period, the greater the guarantee of safety. However, in reality, especially in seismically active regions, it is impossible to guarantee the complete stability of the technical condition of the track during these periods of time. Therefore, it is impossible to guarantee complete safety of the track. Obviously, to solve the track safety problem, it is necessary to take into account changes in the seismic situation in those time intervals in some hauls. This, in turn, requires a continuous monitoring of the beginning of changes in the technical condition of the track using simple and inexpensive technical tools installed in the corresponding cars of the rolling stock. This paper considers one of the possible solutions to this problem. It is known [2-5] that by analyzing soil vibration caused by the impact of the rolling stock, it is possible to form informative attributes that can be used to determine the technical condition of the track. However, the use of traditional correlation, spectral and other analysis technologies proved to be ineffective for the formation of corresponding attributes of informative attributes by analyzing vibration signals. This is due to the fact that, substantial errors caused by the effects of the noise of vibration signals arise, decreasing the adequacy of the results of track control. In this paper, the technology of separate analysis of the useful vibration signal, the noise of the vibration signal, and the relationship between them are proposed to eliminate this difficulty, and on their basis, one of the possible options for constructing intelligent technical means of Noise control is proposed, which can be easily implemented in one of the cars of all rolling stocks. Noise here is used as a carrier of diagnostic information, which is used to form a set of informative attributes that allow identifying the beginning of a change in the technical condition of railroad tracks, bridges and other track elements. For instance, with a combination of well-known technologies, it is possible to build a hybrid system for Noise signaling of the beginning of the latent period of changes in the technical condition, making it possible to prevent sudden destruction of large bridges and other elements of main traffic arteries.

In conclusion, it should be noted that, despite the influence of various factors that make it difficult to ensure fail-safe operation of the running gear of the rolling stock, currently used technologies and systems provide satisfactory control of their operation. However, due to the extreme importance of this issue, to control current state of the running gear of the rolling stock, it is advisable to duplicate traditional control algorithms with the proposed algorithms for the noise control of the onset and development dynamics of malfunctions. This can ensure early diagnostics of such malfunctions of the running gear of the rolling stock as bearing defects, lacking and insufficient lubrication, malfunctions of wheel-and-motor units, mounting defects, imbalance of rotating parts, gear defects, leakage in the feed and brake lines, break valve malfunctions, brake cylinder malfunctions, compressor malfunctions, etc. Thus, the use of algorithms and technology of noise control in combination with traditional algorithms and technologies can significantly enhance the effectiveness and reliability of ensuring fail-safe operation of the rolling stock.

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