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Possibility of increasing safety in the East-West transport corridor by using adaptive intelligent vibration control systems

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Abstract. It is shown that improving the level of safety of the East-West transport corridor first of all requires further development of intellectualization of rail transport. For this purpose, it is necessary to develop effective information technologies that allow building a multifunctional intelligent traffic safety system. In this case of particular importance is the development of:

- intelligent systems to control the beginning of malfunctions of rolling stock, railroad tracks, bridges, tunnels and communication hubs of the entire route;
- intelligent subsystems to control the dynamic of development of emergency state of rolling stock and railroad tracks.

To solve these problems, it is advisable to create a technology to monitor malfunctions of the railroad tracks by changes in the ratio of estimates of the variance of the total signal, useful signal and noise of the noisy vibration signal and by changes in the estimates of the cross-correlation function between the useful signal and the noise. On their basis, it is advisable to create simple and inexpensive intelligent technical means, which can be installed on one of the cars of each rolling stock, which will send signals to the traffic safety centre from the trains in the corresponding sections, which should be monitored out of "turn". Safe and uninterrupted movement of trains also requires ensuring continuous control of the technical condition of the track ballast—the subgrade under the ballast and sloping areas of the railbed—during the movement of the rolling stock. Development and practical application of intelligent systems of signaling of the beginning of the latent period of accidents using diagnostic information contained in the vibration signals can be considered a priority.

***Keywords*:** *vibration control; railroad tracks; informative attributes; diagnostic information; useful signal; noise; control system; signaling; traffic safety; transport corridor*

1. INTRODUCTION

Analysis has shown that at present the safety of the East-West transport corridor primarily requires increasing the level of intellectualization of rail transport. For this purpose, it is necessary to create effective information technologies that allow building a multifunctional intelligent traffic safety system.

It is known that in recent years, the intellectualization of rolling stock equipment diagnostics systems is the main route of their improvement [1-3]. At present, various technologies and diagnostic tools are successfully used in rail transport safety systems. In them, technologies of analysis of vibration, pressure, force, current, voltage, resistance, time intervals, etc. are used to form informative attributes of malfunctions. Of these parameters, vibration signals carry the most information, since a malfunction of most of the rolling stock equipment leads to the occurrence of mechanical vibrations [3-7]. Therefore, the diagnosis of their condition and assessment of the damage hazard degree on the basis of the data of adaptive control in real time is the most important relevant problem.

2. PROBLEM STATEMENT

At present, it is necessary to create effective smart technologies to ensure the safety of the East-West transport corridor. Lack of early diagnosis is one of the main causes of accidents on rolling stock and railroad tracks. Therefore, it is advisable to create intelligent systems with additional functions:

- Intelligent systems to control the beginning of malfunctions of rolling stock, railroad tracks, bridges, tunnels and communication hubs of the entire route;
- Intelligent subsystems to control the dynamic of development of emergency state of rolling stock and railroad tracks.
- Technology of adaptive vibration control.

To solve this problem, it is necessary first of all to provide early diagnosis of the following malfunctions:

- leakage in the feed and brake mains
- break valve malfunctions
- brake cylinder malfunctions
- compressor malfunctions
- bearing defects
- lacking and insufficient lubrication
- bearing misalignments
- mounting defects
- imbalance of rotating parts
- gear defects

Vibration signals $g(i\Delta t)$ obtained from vibration sensors installed on the corresponding equipment, as a rule, have a complex stepwise and abruptly changing form and are accompanied by considerable noise $\varepsilon(i\Delta t)$. Currently, are spectral methods and algorithms are used in the diagnostic systems for the analysis of vibration signals $g(i\Delta t)$. However, the adequacy of diagnostic results is not always ensured in practice [1, 8, 9]. This is due to the fact that in the analysis and identification of such vibration signals $g(i\Delta t)$, their oscillation frequencies and spectral composition continuously change depending on the train speed in real operating conditions. This significantly complicates and hinders intellectualization of problems of vibration diagnostics. Therefore, in order to ensure the adequacy of vibration diagnostics, it is necessary to adaptively determine the sampling interval Δt of these signals. Consequently, to intellectualize the solution of problems of rolling stock equipment diagnostics, it is first and foremost necessary to ensure the adaptation of the sampling interval of the vibration signal.

3. CONTROL OF RAILROAD TRACKS MALFUNCTIONS BY CHANGES IN THE RATIO OF ESTIMATES OF THE VARIANCE OF THE TOTAL SIGNAL, USEFUL SIGNALAND NOISE OF THE NOISY VIBRATION SIGNAL

It is known that railroad tracks as a result of continuous movement of trains in the process of operation as a result of the initiation of various defects over time go into a latent period of emergency state [1-4]. Usually this process is reflected in the vibration signals $g(i\Delta t)$ in the form of $\varepsilon(i\Delta t)$, which, when a malfunction occurs, have a correlation with the useful signals $X(i\Delta t)$ [1-3]. Consequently, during this period the total noise $\varepsilon(i\Delta t)$ forms from the noise $\varepsilon_1(i\Delta t)$, which arises from the influence of external factors and from the noise $\varepsilon_2(i\Delta t)$, caused by the initiation of various malfunctions. The variance of the vibration signal here looks as follows:

$$D_g \approx R_{gg}(0) \approx \frac{1}{N}\sum_{i=1}^{N} g^2(i\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} X^2(i\Delta t) + 2\frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)\varepsilon(i\Delta t) + \frac{1}{N}\sum_{i=1}^{N} \varepsilon^2(i\Delta t) \approx$$
$$\approx R_{XX}(0) + 2R_{X\varepsilon}(0) + R_{\varepsilon\varepsilon}(0).$$

It is also known from literature [1-4] that in this case the formula for determining the estimate of the correlation function of the vibration signal $R_{gg}(\mu)$ can be represented as:

$$R_{gg}(\mu) \approx \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)g((i+\mu)\Delta t) \approx \frac{1}{N}\sum_{i=1}^{N} (X(i\Delta t)+\varepsilon(i\Delta t))(X((i+\mu)\Delta t)+\varepsilon((i+\mu)\Delta t)) \approx$$
$$\approx \frac{1}{N}\sum_{i=1}^{N}[X(i\Delta t)X((i+\mu)\Delta t) + \varepsilon(i\Delta t)X((i+\mu)\Delta t) + X(i\Delta t)\varepsilon((i+\mu)\Delta t) + \varepsilon(i\Delta t)\varepsilon((i+\mu)\Delta t) \approx$$
$$\approx R_{XX}(\mu) + R_{\varepsilon X}(\mu) + R_{X\varepsilon}(\mu) + R_{\varepsilon\varepsilon}(\mu) \approx \begin{cases} R_{XX}(0) + 2R_{X\varepsilon}(0) + R_{\varepsilon\varepsilon}(0) when\, \mu = 0 \\ R_{XX}(\mu) + 2R_{X\varepsilon}(\mu) when\, \mu \neq 0 \end{cases}$$

Where $g(i\Delta t)$ is the noisy vibration signal, $X(i\Delta t)$ is the useful vibration signal, Δt is the sampling interval, D_g is the variance of the noisy signal $g(i\Delta t)$, $R_{gg}(\mu)$ is the correlation function of the signal $g(i\Delta t)$, $R_{X\varepsilon}(\mu)$ is the cross-correlation function between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$, $R_{\varepsilon\varepsilon}(0)$ is the variance of the noise $\varepsilon(i\Delta t)$.

Studies have shown [1-4] that during the operation of railroad tracks during the latent period of accidents estimates $R_{X\varepsilon}(\mu)$, $R_{\varepsilon\varepsilon}(\mu)$ are tangible values, i.e. the following inequality takes place:

$$\begin{cases} R_{X\varepsilon}(\mu) >> 0 \\ R_{\varepsilon\varepsilon}(\mu) >> 0 \end{cases}$$

and therefore there is a significant error in the estimates of D_ε and $R_{gg}(\mu)$.

Because of this, there is a difficulty in ensuring the adequacy of the control results using traditional technologies. This is one of the factors preventing the use of traditional technologies of analysis of noisy signals for control of malfunctions of railroad tracks. In view of this, there is a need to develop technologies and technical means for monitoring and signaling the beginning of the latent period of accidents on the railroad track that would not suffer from the above disadvantages.

It is known [4-10] that a change in the technical condition is primarily reflected in the estimates of the above characteristics of the total signal $g(i\Delta t)$ obtained from the ground vibration resulting from the impact of the rolling stock. In this case, the variance of the useful signal D_X and the variance of the interference D_ε, are determined from the following known expressions:

Studies have shown that in this case an effective informative attribute of the beginning of a track malfunction is the coefficients derived from the correlation of estimates, which are determined from the formulas:

$$K_1 = \frac{D_X}{Dg}, K_2 = \frac{D\varepsilon\varepsilon}{D_g}, K_3 = \frac{D\varepsilon\varepsilon}{D_X} \quad (1)$$

where

$$D_g = \frac{1}{N}\sum_{i=1}^{N} g^2(i\Delta t), D_X = \frac{1}{N}\sum_{i=1}^{N} X^2(i\Delta t), D_{\varepsilon\varepsilon} = \frac{1}{N}\sum_{i=1}^{N} \varepsilon^2(i\Delta t) \quad (2)$$

It is shown in [1, 2] that the estimates of the variance $D_{\varepsilon\varepsilon}$ of the total noise $\varepsilon(i\Delta t)$ can be determined from the expression:

$$D_{\varepsilon\varepsilon} \approx R_{\varepsilon\varepsilon}(0) \approx \frac{1}{N}\sum_{i=1}^{N}\left[g^2(i\Delta t) + g(i\Delta t)g((i+2)\Delta t) - 2g(i\Delta t)g((i+1)\Delta t)\right]$$

This allows us to determine the estimate of the variance of the useful signal $X(i\Delta t)$ from the formula:

$$D_X = D_g - D_{\varepsilon\varepsilon}.$$

Thus, by determining the estimates of D_g, D_X, $D_{\varepsilon\varepsilon}$, it is possible to determine from formula (1) the estimates of the coefficients K_1, K_2, K_3 which can be used as informative attributes in the building of the railroad track malfunction signaling system.

4. TECHNOLOGIES FOR SIGNALING OF THE BEGINNING OF THE LATENT PERIOD OF MALFUNCTION OF RAILROAD TRACKS

To exclude the possibility of catastrophic accidents due to the malfunction of the railroad tracks, it is necessary to ensure continuous control with the duplication of several simple and reliable technologies of signaling the beginning of this process [5-10]. In this case one of the important informative attributes of control is the emergence of a correlation between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ of vibration signals $g(i\Delta t)$ at the beginning of the latent period of accidents. Studies have shown that for this purpose it is advisable to use the estimates of the relay cross-correlation functions $R_{X\varepsilon}(\mu=0)$ between the useful vibration signal $X(i\Delta t)$ and noise $\varepsilon(i\Delta t)$ which can be calculated using the formula [1, 2]

$$R^1_{X\varepsilon} \approx \frac{1}{N}\sum_{i=1}^{N} \operatorname{sgn} g(i\Delta t) g^2(i\Delta t). \tag{2}$$

It can be shown that the result of calculation using this formula (2) is an approximate estimate of the relay cross-correlation function $R^1_{X\varepsilon}$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$.

To this end, taking the known notation and the condition

$$\operatorname{sgn} g(i\Delta t) = \begin{cases} +1 & when \quad g(i\Delta t) > 0 \\ 0 & when \quad g(i\Delta t) = 0 \\ -1 & when \quad g(i\Delta t) < 0 \end{cases},$$

taking into account the known equations [1, 2]

$$\begin{cases} \operatorname{sgn} g(i\Delta t) = \operatorname{sgn} X(i\Delta t) \\ \operatorname{sgn} g(i\Delta t)\cdot g(i\Delta t) = \operatorname{sgn} X(i\Delta t)\cdot\left[X(i\Delta t)+\varepsilon(i\Delta t)\right] \end{cases},$$

$$\operatorname{sgn} g(i\Delta t)\cdot g^2(i\Delta t) = \operatorname{sgn} X(i\Delta t)\cdot g^2(i\Delta t),$$

$$\frac{1}{N}\sum_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\cdot g^2(i\Delta t) = 0$$

and assuming the validity of the following equality at $\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t)$:

$$\begin{cases} \dfrac{1}{N}\sum\limits_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\cdot X^2(i\Delta t) = 0 \\ \dfrac{1}{N}\sum_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\cdot 2X(i\Delta t)\varepsilon(i\Delta t) = 0 \\ \dfrac{1}{N}\sum\limits_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\cdot \varepsilon^2(i\Delta t) = 0 \end{cases}$$

we can see that formula (2) is valid, i.e.

$$R^1_{X\varepsilon}\ \frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)\cdot g^2(i\Delta t)=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)\cdot\left[X(i\Delta t)+\varepsilon(i\Delta t)\right]^2=$$
$$=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)\cdot X^2(i\Delta t)+\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)\cdot 2X(i\Delta t)\varepsilon(i\Delta t)+$$
$$+\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)\cdot\varepsilon^2(i\Delta t)=0.$$

However, a malfunction of the track causes the noise $\varepsilon_2(t)$ to emerge, which correlates with the useful signal $X(i\Delta t)$. As a result, there is a correlation between the total noise $\varepsilon(i\Delta t)=\varepsilon_1(i\Delta t)+\varepsilon_2(i\Delta t)$ and the useful signal $X(i\Delta t)$ and because of this the estimate $R^1_{X\varepsilon}$ differs from zero, i.e. the following equalities hold:

$$R^1_{X\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)\cdot g^2(i\Delta t)=\begin{cases}0, \textit{when} & \varepsilon(i\Delta t)=\varepsilon_1(i\Delta t)\\ R_{X\varepsilon}(0), \textit{when} & \varepsilon(i\Delta t)=\varepsilon_1(i\Delta t)+\varepsilon_2(i\Delta t)\end{cases}$$

Due to this, the estimate $R^1_{X\varepsilon}$ obtained from expression (2) can be used as an informative attribute in control systems for signaling the beginning of malfunction.

However, in order to improve the reliability of the results of signaling the beginning of a malfunction of railroad tracks, as shown in the problem statement, it is reasonable to parallelize this technology with other technologies. It is shown in the literature [1, 2] that the estimate of relay cross-correlation function $R^2_{X\varepsilon}$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ can also be calculated from the expression

$$R^2_{X\varepsilon}=R^*_{gg}(\mu=0)-2R^*_{gg}(\mu=1)+R^*_{gg}(\mu=2),\tag{3}$$

which can also be represented as

$$R^2_{X\varepsilon}=\frac{1}{N}\sum_{i=1}^{N}\left[\operatorname{sgn} g(i\Delta t)g(i\Delta t)-2\operatorname{sgn} g(i\Delta t)g((i+1)\Delta t)+\operatorname{sgn} g(i\Delta t)g((i+2)\Delta t)\right].$$

Here, taking into account the equality

$$R^*_{gg}(\mu=0)=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)g(i\Delta t)=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)g(i\Delta t),$$
$$R^*_{gg}(\mu=1)=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)g((i+1)\Delta t)=\frac{2}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)g((i+1)\Delta t),$$
$$R^*_{gg}(\mu=2)=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} g(i\Delta t)g((i+2)\Delta t)=\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)g((i+2)\Delta t).$$

formula (3) can also be represented as

$$R^2_{X\varepsilon}\approx\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)g(i\Delta t)-\frac{1}{N}\sum_{i=1}^{N}2\operatorname{sgn} X(i\Delta t)g(i+1)\Delta t+\frac{1}{N}\sum_{i=1}^{N}\operatorname{sgn} X(i\Delta t)g((i+2)\Delta t),\tag{4}$$

where

$$g(i\Delta t)=X(i\Delta t)+\varepsilon(i\Delta t)$$
$$g(i+1)\Delta t=X((i+1)\Delta t)+\varepsilon((i+1)\Delta t)$$
$$g(i+2)\Delta t=X((i+2)\Delta t)+\varepsilon((i+2)\Delta t)$$

In this case, before a malfunction, the following equalities are true

$$\begin{cases} R^*_{X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\varepsilon(i\Delta t) = 0 \\ R^*_{X\varepsilon}(\Delta t) = \frac{1}{N}\sum_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\varepsilon((i+1)\Delta t) \approx 0 \\ R^*_{X\varepsilon}(2\Delta t) = \frac{1}{N}\sum_{i=1}^{N} X(i\Delta t)\varepsilon((i+2)\Delta t) \approx 0 \end{cases}$$

and due to this the estimate of $R^2_{X\varepsilon}$ will be zero, i.e.

$$R^2_{X\varepsilon} \approx R^*_{gg}(0) + R^*_{gg}(2\Delta t) - 2R^*_{gg}(\Delta t) \approx 0 .$$

If a malfunction occurs due to additional error $\varepsilon_2(i\Delta t)$, a correlation emerges between $X(i\Delta t)$ and $\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t)$, and the following inequality takes place:

$$R^*_{X\varepsilon}(0) = \frac{1}{N}\sum_{i=1}^{N} \operatorname{sgn} X(i\Delta t)\varepsilon(i\Delta t) \neq 0$$

which is why the informative attribute $R^2_{X\varepsilon}$ is non-zero, i.e

$$R^2_{X\varepsilon} = R^*_{gg}(0) + R^*_{gg}(2\Delta t) - 2R^*_{gg}(\Delta t) \neq 0 .$$

Thus, when a malfunction occurs, the estimate of $R^2_{X\varepsilon}(0)$ will be non-zero. Consequently, during the period of normal technical condition of the tracks due to the lack of correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the estimate of the relay cross-correlation function $R^2_{X\varepsilon}$ between the useful signal and the noise both by expression (3), and by expression (4) will be close to zero. It is also obvious that because malfunctions are caused by the additional 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 function $R^2_{X\varepsilon}$, due to the correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, will be non-zero. Thus, the estimate obtained by expression (3), (4) is the estimate of the relay cross-correlation function $R^2_{X\varepsilon}$ between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ which can also be used as an informative attribute to signal a malfunction. The distinctive feature of this algorithm is in that even violations of such classical conditions as the normality of the distribution law and stationarity of vibration signals $g(i\Delta t)$ during the initiation of various malfunctions affects the obtained estimate insignificantly. Therefore, when there is a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$, the estimate of $R^2_{X\varepsilon}$ can be used to control the onset of accidents. This increases the reliability of the signaling system.

5. TECHNOLOGY OF CONTROL OF THE BEGINNING AND THE DEGREE OF DEVELOPMENT OF MALFUNCTIONS OF RAILROAD TRACKS

As shown above, at the beginning of the latent period of track malfunction caused by the additional noise $\varepsilon_2(i\Delta t)$, the estimate of the cross-correlation function $R_{X\varepsilon}(0)$ between the useful signal $X(i\Delta t)$ and the total noise $\varepsilon(i\Delta t) = \varepsilon_1(i\Delta t) + \varepsilon_2(i\Delta t)$ is non-zero. An analysis of different variants of the occurrence of malfunctions shows that when controlling them, it is also advisable to control the degree of their development. Naturally, over a long period of time with a stable initial emergency state, this estimate does not change. However, with the lapse of time with the development of the malfunction, this estimate changes, and therefore, it is possible, in addition to monitoring the presence of a malfunction, to control the degree of accident development. Analysis [3-6] shows that, depending on the degree of development of accidents on the railroad tracks, a correlation between the useful signal $X(i\Delta t)$ and the noise $\varepsilon(i\Delta t)$ emerges at 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. This is due to the fact that the development of accidents leads to an increase in the duration of the correlation in time, i.e., at the beginning there is correlation between $X(i\Delta t)$ and $\varepsilon(i+1)\Delta t$. Then further development of the malfunction results in correlation between $X(i\Delta t)$ and $\varepsilon(i+2)\Delta t$, and then also between $X(i\Delta t)$ and $\varepsilon(i+3)\Delta t$, etc. Therefore, when controlling the degree of development of the track malfunction, it is necessary to calculate estimates corresponding to the cross-correlated function between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$. In works [1-3] it is shown that it is possible to calculate the estimate of $R_{X\varepsilon}(\Delta t)$ in the presence of correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at $\mu = \Delta t$ from the expression

$$R^4_{X\varepsilon} \approx \frac{1}{N}\sum_{i=1}^{N}[g(i\Delta t)g(i+1) - 2g(i\Delta t)g((i+2)\Delta t) + g(i\Delta t)g((i+3)\Delta t)]. \tag{5}$$

The estimate of $R_{X\varepsilon}(2\Delta t)$ in the presence of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at $\mu = 2\Delta t$ can be similarly calculated using the expression

$$R^5_{X\varepsilon} \approx \frac{1}{N}\sum_{i=1}^{N}[g(i\Delta t)g(i+2) - 2g(i\Delta t)g((i+3)\Delta t) + g(i\Delta t)g((i+4)\Delta t)]. \tag{6}$$

In the case of a correlation between $X(i\Delta t)$ and $\varepsilon(i\Delta t)$ at *m* different time shifts $\mu = m\Delta t$, $m = 1,2,3,...$ the following generalized expression is true:

$$R^5_{X\varepsilon} \approx \frac{1}{N}\sum_{i=1}^{N}\left[g(i\Delta t)g((i+m-1)\Delta t) - 2g(i\Delta t)g((i+m)\Delta t) + g(i\Delta t)g((i+m+1)\Delta t)\right]. \tag{7}$$

Obviously, the possibility of calculating the estimates of $R_{X\varepsilon}(\mu = 1\Delta t), R_{X\varepsilon}(\mu = 2\Delta t), R_{X\varepsilon}(\mu = 3\Delta t),..., R_{X\varepsilon}(\mu = m\Delta t)$ allows us to use them to control not only the beginning, but also the degree of further development of accidents.

Thus, as follows from the above, the use of algorithms (5), (6), (7) allows determining the appropriate informative attributes that can be used in the control of both the beginning and the degree of development of malfunctions of railroad tracks

6. CONCLUSION

It is common knowledge that the dynamic process from ground vibration occurring during the movement of trains on the railroads is reflected in the vibration signals. Therefore, this feature of vibration signals $g(i\Delta t)$ is of great practical interest because they can be used to signal the beginning of a malfunction of the tracks, which will increase the degree of accident-free operation of rail transport. Because of this, solving the problem of development and practical application of intelligent systems of signaling of the beginning of the latent period of accidents using diagnostic information contained in the vibration signals can be considered a priority [4-10]. For safe and uninterrupted movement of trains, it is necessary to ensure continuous control of the technical condition of the ballast layer, which is the main platform under the ballast and slope areas of the earth bed during the movement of the rolling stock. In this case, to analyze the vibration signals arising during the movement of trains on the railroads, it is advisable to use hybrid technology with a combination of different informative attributes of monitoring the beginning of this process. This makes it possible to increase the degree of reliability of control results by parallelizing the control process with the use of several algorithms and to assess the degree of their reliability based on the number of matching results about the presence of a malfunction.

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