Selective suppression of amplitudes of frictional oscillations

V I Kolesnikov¹*, V V Shapovalov², A L Ozyabkin², M M Shestakov², R A Kornienko², T D Pertseva³ and A M Petrik³,⁴

¹ Department of Theoretical mechanics, Rostov State Transport University, Rostov-on-Don, pl. Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya, 2, 344038, Russia
² Department of Transport machines and Tribotechnology, Rostov State Transport University, Rostov-on-Don, pl. Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya, 2, 344038, Russia
³ Faculty of road construction machines, Rostov State Transport University, Rostov-on-Don, pl. Rostovskogo Strelkovogo Polka Narodnogo Opolcheniya, 2, 344038, Russia
⁴ Author to whom any correspondence should be addressed, *e-mail: adad98999@mail.ru

Abstract. Maintenance of sanitary codes and standards during operation of railway sorting stations, in particular, standards which concern noise levels, is now the most pressing task. The analysis of noise has been carried out during operation of brake beams of car hump retarders with car wheelsets; the most problem frequency ranges have been revealed. On the basis of modelling bench tests with application of techniques of physical and mathematical modelling and tribospectral identification of friction processes we carried out selection of noise-suppressing cladding material which would reduce the level of acoustic noise at interaction of metal surfaces. Results of operational trials have confirmed efficiency of the chosen material in noise reduction.

1. Introduction

People have always lived in the world of sounds and noise. In nature loud sounds are rare; noise is rather weak and short. Normal noise of environment surrounding the person varies within 35-60 dB, where dB is a measuring unit of noise or sound pressure. The combination of sound stimuli gives time to a person for an estimation of their character and response. Growth of urban population, and construction of the industrial enterprises in the former suburbs of urban areas cause increase in levels of sound pressure [1] to acoustic organs of people, 1.5-2 times exceeding admissible norms. Sounds and noise of high-power expose people’s health, and can cause pain; they can also affect hearing aid and nerve centres, and provoke adverse effects on performance of cardiovascular system and other human organs. The above-listed enterprises include stations and railway junctions that are characterized by increased rolling noise and vibration levels caused by wheel and induced at the wheel-rail contact. There are some effective ways to reduce the harmful effects on individuals, for instance, constructive solutions for damping the track structure and operating brake marshalling complexes at mechanized marshalling yards.

These days the most technologically advanced countries are actively engaged in improving the eco-friendliness of technical systems, including reducing noise and vibration [2-10]. For example, “Living Well, Within the Limits of Our Planet” Environment Action Program [11], which is guiding European
environment policy until 2020, sets out commitments to reduce noise pollution in the European Union and to reach the World Health Organization-recommended level by 2020. Due to the high level of noise and vibrations induced by ICEs, in particular, the engines of the MI 26 helicopter, the suppression of these dynamic processes is a complex, yet an extremely important and urgent task. Currently, the below-mentioned methodology has become the ground for creating a set of structural and technological measures aimed at improving the technical, economic and environmental characteristics of the MI 26 helicopter power actuator.

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ELPA company has developed BREMEX-ANNSYS system [12] for noise level reduction up to 30 dB at sorting stations. The system works in such a way that special composite material DBM for dry braking is applied precisely to car wheels or to where braking takes place before there is a frictional contact between them. This eliminates oscillations in a range of resonant frequencies. Since a considerable quantity of energy is released in the form of heat during friction between wheels and rails, the auxiliary component of the composite material evaporates, whereas the working component (more often it is aluminium) creates an abrading brake film which removes a grinding sound in its source. BREMEX-ANNSYS system has some drawbacks. First, it has microprocessor control which considerably increases capital investments to the equipment of one brake position (300 thousand euro); then, it is impossible to use this system under conditions of considerable environmental change: air temperatures (from -50 °C to +50 °C), wind loading P (from P_0 to P_{max}), atmospheric precipitation in the form of rain and snow; next, evaporations of auxiliary component reduce ecological safety; finally, use of the consumable material (modifier) is exclusively made by ELPA company.

2. Carrying out of tests

The reason of the high noise level appearing during car hump retarder of mechanised sorting station is resonant oscillations and frictional self-oscillations occurring during interaction of micro- and macroroughnesses of side faces of wheels of freight cars with operating surfaces of brake beams. In this case it is possible to present micro- and macroroughnesses in the form of a model of individual roughness (figure 1), consisting of two dynamic equivalent single mass systems with natural frequencies

$$\omega_1 = \sqrt{\frac{C_1}{m_1}} \text{ and } \omega_2 = \sqrt{\frac{C_2}{m_2}}.$$

In case of coincidence of frequency of dynamic influence of system and one of the frequencies $\omega_1$ or $\omega_2$, there are resonant fluctuations of lumped masses $m_1$ or $m_2$ (or $m_1$ and $m_2$).

![Figure 1. Model of individual roughness](image-url)
The principal cause of origination of frictional self-oscillations consists in nonlinear dependence of frictional forces $F_{ff}$ that happen due to more than 40 factors. To reveal the reasons of origination of oscillations and selection of noise-suppressing cladding material we carried out field investigations and modelling bench tests.

We used a special device EKOFIZIKA-110A (ecophysics – 110A) to check in levels of sound pressure during performance of a car hump retarder at the mechanised sorting station. To reveal frequency range where level of sound pressure exceeds sanitary codes and standards, we carried out tests using dictaphone Olympus WS-853 and software that performs octave spectral analysis.

As a result of 1/12-octave analysis (figure 2) of the noise appearing during interaction of wheels of cars with brake beams at mechanised hump yards of the railway stations Bataysk (the North Caucasian railway), it has been established that the high noise level is observed on the frequencies exceeding 2 000 Hz, and acoustic waves of high power are observed on center resonant frequencies of 2 986 and 5 625 Hz.

For carrying out of bench tests on selection of lubrication and elimination of resonant oscillations and frictional self-oscillations during interaction of brake tyres of a car hump retarder with wheels of cars, we used physical and mathematical modelling [13] and engineering test bed «rolling stock - track», executed in geometrical scale $C_i = 5$. Thus, we reproduced similar loading-speed conditions of interaction on the scale of forces of normal and tangential interactions $C_N = C_T^2$, sliding velocities $C_v = 1$, contact pressure $C_Q = 1$, frequencies of natural fluctuations $C_\omega = 1$ both on micro - and on macro - levels of frictional interaction.

Traditionally, friction factor is represented in the form of the static relation of average frictional force to average force of safe pressure $\mu = \frac{F_{ff}}{N}$; unlike that, the result of interaction of forces of friction and on every frequency of harmonious fluctuation with frequency $\omega$ in the form of transfer function

$$W(i\omega) = \frac{S_{\Re}(i\omega) \cdot S_{NN}(-i\omega)}{|S_{NN}(i\omega)|^2} = \frac{S_{2N}(i\omega)}{S_{NN}(i\omega)} = A(\omega) \cdot e^{i\varphi(\omega)} = P(\omega) + iQ(\omega),$$

where $S_{NN}(\omega)$ is autospectral function of normal influence in frictional contact taking into consideration the uncontrollable power noise disturbing stationary movements of the system; $S_{2N}(i\omega)$ is the spectral function of mutual tangential and normal interaction taking into consideration uncontrollable power noise, properties of triboconditions and the external conditions influencing the system; $A(\omega)$ is amplitude-frequency characteristic

$$A(\omega) = |W(i\omega)| = \sqrt{P^2(\omega) + Q^2(\omega)};$$

$\varphi(\omega)$ is phase and frequency characteristic

$$\varphi(\omega) = \arctg(Q(\omega)/P(\omega));$$

$P(\omega)$ is material frequency characteristic that describes elastic-inertial properties of the system, or potential kinetic energy

$$P(\omega) = Re\{W(i\omega)\} = A(\omega) \cdot \cos[\varphi(\omega)];$$

$Q(\omega)$ is imaginary frequency characteristic that describes dissipative losses in tribosystem, or function of energy dispersion

$$Q(\omega) = Im\{W(i\omega)\} = A(\omega) \cdot \sin[\varphi(\omega)];$$

$\omega$ is periodic signal frequency.

The result of calculations of frequency transfer function (1) is the set of amplitude and phase-frequency characteristics (figure 3) that correspond to a variety of statuses of frictional contact.
Figure 2. Basic 1/12-octave frequency ranges of vibroacoustic noise, appearing during interaction of wheelsets with brake tyres on the mechanised hump yards:
a – on frequency of 2 986 Hz; b–d – on frequency of 5 625 Hz
Figure 3. Frequency characteristics of tribosystem: a – amplitude, and phase; b - amplitude-phase, where integrated values: $m_1, m_2$ are masses of the active microvolumes participating in friction [kg]; $C_1, C_2$ are factors of elastic properties of contact [$\frac{N}{m^3}$]; $\beta_1, \beta_2$ are factors of resistance to fluctuations [$\frac{N\text{ns}}{m}$]; $\omega$ is frequency of fluctuations [$c^{-1}$]; $z_0$ is initial displacement in a normal direction; $x_0$ is initial tangential displacement; $L$ is factor of a stock of stability on amplitude; $\mu_1$ is factor of a stock of stability on a phase

The dynamic friction factor $W(i\omega)$ varies from 0 to $\infty$ depending on prevalence of elastic or dissipative component, presence or suppression of dynamic processes. For example, in case of realisation of modes of athermal or thermal adhesion, the friction factor tends to infinity, and in case of creation of resonant fluctuations it tends to zero (Tolstoi-Push effect).

Integrated estimation was suggested to identify friction and wear processes in frictional contact area and to select noise-suppressing cladding material on the basis of the analysis of amplitude and phase-frequency characteristics (figure 3). This integrated estimation allows estimating a ratio of elastic-inertial and dissipative forces of frictional interaction, stability, and irreversibility conditions in the contact area. For example, the integrated estimation of a dissipative component of friction $I_Q$, defining dissipative properties of a mechanical subsystem and friction process as dynamic connection [13]

$$I_Q = \int_{\omega_l}^{\omega_u} |Q(\omega)| d\omega,$$

where $\omega_l, \omega_u$ are boundary frequencies during octave analysis or 1/3-, 1/12-, 1/24- octave analysis.

Using above-mentioned research techniques of the nonlinear processes taking place in frictional contact area including accompanying frictional self-oscillations, we carried out a model optimisation of five variants of noise-suppressing cladding materials. After the analysis of the received data we selected the composition based on a natural thermoplastic-adhesive. A dissipative component of frictional interaction of the given composition on problem CPB frequency ranges of the frictional self-oscillations appearing during interaction of operating devices car hump retarder with wheel side faces of freight car wheel is on 25-30 % more than that of the other investigated variants. The given composition has been chosen as a basic one.

We have developed three schemes of technical solution to creation of process equipment for application of thermoplastic-adhesive. As the optimum scheme of the device for cladding a wheel side
face we chose the design with an arrangement of briquettes of modifiers in the body of operating devices of standard car hump retarders (figure 4).

![Figure 4. Brake shoe: 1 - noise-suppressing cladding material; 2 - beam case of retarder; 3 - friction facing](image)

Modifying process is carried out by feeding noise-suppressing cladding material from the cavities which are located in bodies of a friction pair (for example, in a friction facing body) during wear-out of the body in contact process with another body (with its operating surface, for example, with a lateral surface of a wheel of a freight car). The necessary quantity of noise-suppressing cladding material is determined by intensity of wear process of friction surface of the first body (with cavities and with noise-suppressing cladding material). In its turn, the intensity of wear process is determined by a ratio of the sectional area of cavities with noise-suppressing cladding material $S_1$ to the contact area of material of the first body $S_2 = S_{\Sigma} - S_1$, where $S_{\Sigma}$ is the area of a friction surface.

Real-life tests of the experimental device on noise reduction at the mechanised hump yards and on application of the modifier to a friction surface on lateral sides of wheelsets were carried out with use of empty and loaded freight cars with weight of 69-70 tons. As a result of interaction of wheelsets of freight cars with brake beams, we fixed formation of a modifying covering on brake beams of the device (figure 5) and egress of noise-suppressing cladding material (NSCM) from special accumulators on lateral sides of wheelsets (figure 6).

After the device applied successfully noise-suppressing cladding material on wheelsets of the freight cars, they retarded in a regular mode from a hump yard. By means of EKOFIZIKA-110A we made the octave analysis of the noise appearing within a distance of 2 and 7.5 m from retarder positions (table 1) during sorting of freight cars with modifiers of friction surface applied to lateral sides of wheelsets.

| Table 1. The octave analysis of the noise appearing during operation of car hump retarder |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Frequency, Hz (average of 10 tests) |
| 31.5 | 63 | 125 | 250 | 500 | 1,000 | 2,000 | 4,000 | 8,000 | 16,000 |
| L = 2 m | 56.1 | 53.4 | 49.9 | 48.7 | 52.3 | 49.9 | 51.2 | 49.4 | 46.8 | 40.8 |
| L = 7.5 m | 41.9 | 44.3 | 42.8 | 47.7 | 52.7 | 44.6 | 40.4 | 41.9 | 44.3 | 42.8 |
Figure 5. Configuration of system of axis drive of noise-suppressing cladding material (NSCM) on tracks of Bataysk permanent way division

Figure 6. Modifier of a friction surface on lateral sides of the freight car wheels

It is established that at the admission of the test car to all three retarder positions of the mechanised hump yard the noise suppression has been revealed on all frequency ranges up to the level which is not exceeding sanitary codes and standards.

3. Conclusions
The following conclusions have been drawn as a result of the analysis of the operational trials.

1) The experimental design of the device provides application of necessary quantity of noise-suppressing cladding material onto a side face of car wheels; it provides reduction of noise (which appears at interaction of brake beams with disks of wheelsets) to the values which are not exceeding admissible sanitary codes and standards.

2) Due to an intake device and absence of connections in a horizontal plane, the complex design well adjusts (is guided) to the freight car wheels which side face is modified by the device for reduction of noise level.

3) Due to application of the experimental device of an axis drive system of noise-suppressing cladding material before the first brake position we can evidence a drop of levels of sound pressure and noise from 85 ... 97 dB to 40 ... 52 dB in octave frequency bands to the values regulated by sanitary codes and standards.
4) The rotaprint and contact method of application of noise-suppressing cladding material provides reliable and effective operation of the device in a wide temperature range (from -50 °C to +50 °C) and presence of wind loading, providing thus ecological cleanliness as a result of absence of effects of greasing of surfaces of rails and rolling stock.

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