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DERIVING THE DEPENDENCIES FOR THE VIBRATING CAPACITY INTRODUCED INTO WHEELSET ASSEMBLIES

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***Abstract**: Despite the very large difference in lifting capacity, bridge cranes have an almost identical vibration control system layout, which predetermines the general approach to the theoretical assessment of vibration and noise spectra both in the production premises and at the crane operator's workplace. The bridge crane is characterized by potential danger for not only operators but also production personnel located in the crane area within the production workshop during its operation. The safe operating conditions of cranes are determined by not only their technical condition but also the crane operator fatigue, which, in turn, is caused mainly by the impact of increased noise and vibration.*

***Keywords:** bridge cranes, noise levels, vibration, sanitary standards, wheelset assemblies*

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1. INTRODUCTION

An analysis of the layouts of all bridge crane types allows suggesting that wheelset assemblies are among the main sources of increased noise.

2. EQUIPMENT AND DEVICES USED IN THE RESEARCH

The wheels are actually emitters in the form of round plates with relevant inertia moments. For such sources, sound pressure and power levels are determined by the following equations:

$$L_{W_k} = 20lgV_k + 10\,lg(0.5\mathrm{D}_k + h_k)\,k + 174 \quad (1)$$

where
D_k is the wheel diameter, m;
h_k is the wheel rim thickness, m;
k is a coefficient determining the vibration eigenfrequency.

The vibration eigenmodes of the wheelset axles are defined considering their geometric configuration as follows:

$$f_k = 625\left(\frac{k}{l}\right)^2 \mathrm{D}_0 \quad (2)$$

Then the following dependencies are obtained for the sound power levels:

- for two wheelset axles at : $0{,}02f_kD_0<1$

$$L_{w_0} = 40lgk\mathrm{D}_0 - 30lgl + 10lgBV_k cos\beta + 183 \quad (3)$$

- or two wheelset axles at: $0{,}02f_kD_0\leq1$

$$L_{w_0} = 40lg\frac{k}{l} + 20lg\mathrm{D}_0 + 10lgBV_k cos\beta + 161 \quad (4)$$

- for four crane trolley wheels:

$$L_{w_k} = 20lgV_k + 10\,lg(0.5\mathrm{D}_k + h_k)\,k + 180 \quad (5)$$

3. RESULTS AND DISCUSSION

Thus, for the engineering calculation of the spectral component levels of the above sources, the amplitudes of vibration velocities in the eigenmode of each source should be determined.

The general approach to calculating the vibration velocities of wheels is based on energy techniques considering the wheelset assembly layout (as a system of two wheels and an axle) [1-11].

It should be noted that the actually introduced vibration capacity depends on both the force action in the wheel-rail system and the vibration speed of the rail itself. In this case, the force action is defined as:

$$P_{\mathrm{i}} = m_{\mathrm{i}} \cdot \left|R_e\{y''\}\right| \quad (6)$$

where
m_i is the mass reduced to each wheel, kg;
P_i is the acceleration of rail vibrations, m/s^2.

When the bridge crane moves, the force action on the wheelset assemblies is transmitted from the rails, the vibration acceleration of which is found as the time derivative of the vibration velocities at their eigenfrequencies, the equations for which are obtained in [1, 2]. Then, for the conditions of installing the rail as a rigidly fixed beam, the acceleration equations will be written as follows:

$$\left|\mathrm{Re}\left\{y_1''\right\}\right|=\left|\frac{2{,}6\cdot10^{-4}Ph_p^3}{F}\cdot\sum_{k=1}^{k^*}\left(\frac{7k-3}{l_1}\right)^4\cos1{,}3\cdot10^4\left(\frac{7k-3}{l_1}\right)^2\sqrt{\frac{I}{F}}t+\right.$$
$$+PVl_1^2\cdot10^{-2}\left\{\sum_{k=1}^{k^*}\frac{\frac{7k-3}{2l_1}\pi V\left[6{,}4\cdot10^7(7k-3)^2\frac{Y}{F}-(Vl_1)^2\right]\sin\frac{7k-3}{2l_1}\pi Vt\cdot\frac{1}{7k-3}}{\left[6{,}4\cdot10^7(7k-3)^2\frac{Y}{F}-(Vl_1)^2\right]^2+4\cdot10^{15}(7k-3)^4\left(\frac{Y}{F}\eta\right)^2}+\right.$$
$$+\frac{\frac{3-5k}{2l_1}\pi V\left[1{,}6\cdot10^8(7k-3)^4\cdot\frac{Y}{F}-(5k-3)^2(Vl_1)^2\right]}{\left[1{,}6\cdot10^8(7k-3)^4\cdot\frac{Y}{F}-(5k-3)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(7k-3)^8\left(\frac{Y}{F}\eta\right)^2}\times$$
$$\times(3-5k)\sin\frac{3-5k}{2l_1}\pi Vt+$$
$$+3{,}6\left(\sum\frac{\frac{3k-1}{2l_1}\pi V\left[1{,}6\cdot10^8(7k-3)^4\frac{Y}{F}-(3k-1)^2(Vl_1)^2\right]}{1{,}6\cdot10^8(7k-3)^4\frac{Y}{F}-(3k-1)^2(Vl_1)^2\,2{,}6\cdot10^{16}(7k-3)^8\left(\frac{Y}{F}\eta\right)^2}\times\right.$$
$$\times(3k-1)\sin\frac{3k-1}{2l_1}\pi Vt+$$
$$+\frac{\frac{1-k}{2l_1}\pi V\left[1{,}6\cdot10^8(7k-3)^4\frac{Y}{F}-(1-k)^2(Vl_1)^2\right]}{1{,}6\cdot10^8(7k-3)^4\frac{Y}{F}-(1-k)^2(Vl_1)^2+2{,}6\cdot10^{16}(7k-3)^8\left(\frac{Y}{F}\eta\right)^2}\times$$
$$\left.\left.t\times(1-k)\sin\frac{1-k}{2l_1}\pi Vt\right)\right\}\sin\frac{7k-3}{2l_1}\pi x\Bigg|;$$

$$\left|\mathrm{Re}\left\{y''_2\right\}\right|=\left|\frac{2\cdot10^{-4}Ph_p^3}{F}\cdot\sum_{k=1}^{k^*}\left(\frac{3-5k}{l_1}\right)^4\cos1{,}3\cdot10^4\left(\frac{3-5k}{l_1}\right)^2\sqrt{\frac{I}{F}}t+\right.$$
$$+PVl_1^2\cdot10^{-2}\left\{\sum\frac{\frac{7k-3}{2l_1}\pi V\left[1{,}6\cdot10^8(3-5k)^4\frac{Y}{F}(7k-3)^2(Vl_1)^2\right]}{\left[1{,}6\cdot10^8(3-5k)^4\frac{Y}{F}-(7k-3)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(7k-3)^8\left(\frac{Y}{F}\eta\right)^2}\times\right.$$
$$\times(7k-3)\sin\frac{7k-3}{2l_1}\pi Vt+$$
$$+\frac{\frac{3-5k}{2l_1}\pi V\left[6{,}4\cdot10^7(3-5k)^2\frac{Y}{F}-(Vl_1)2\right]}{\left[6{,}4\cdot10^7(3-5k)^2\frac{Y}{F}-(Vl_1)^2\right]^2+4\cdot10^{15}(3-5k)^4\left(\frac{Y}{F}\eta\right)^2}\cdot\frac{\sin\frac{3-5k}{2l_1}\pi Vt}{3-5k}+$$
$$+3{,}6\sum\frac{\frac{3k-1}{2l_1}\pi V\left[1{,}6\cdot10^8(3-5k)^4\frac{Y}{F}-(3k-1)^2(Vl_1)^2\right]}{\left[1{,}6\cdot10^8(3-5k)^4\frac{Y}{F}-(3k-1)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(3k-1)^8\left(\frac{Y}{F}\eta\right)^2}\cdot(3k-1)\sin\frac{3k-1}{2l_1}\pi Vt+$$
$$+\sum\frac{\frac{1-k}{2l_1}\pi V\left|1{,}6\cdot10^8(3-5k)^4\frac{Y}{F}-(1-k)^2(Vl_1)^2\right|}{\left[1{,}6\cdot10^8(3-5k)^4\frac{Y}{F}-(1-k)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(3-5k)^8\left(\frac{Y}{F}\eta\right)^2}\times$$
$$\left.\times(1-k)\sin\frac{1-k}{2l_1}\pi Vt\right)\Bigg\}\sin\frac{3-5k}{2l_1}\pi x\Bigg|;$$

$$\left|\mathrm{Re}\left\{y''_3\right\}\right|=\left|-\frac{2\cdot10^{-4}Ph_p^3}{F}\cdot\sum_{k=1}^{k^*}\left(\frac{3k-1}{l_1}\right)^4\cos1{,}3\cdot10^4\left(\frac{3k-1}{l_1}\right)^2\sqrt{\frac{I}{F}}t+\right.$$
$$+PVl_1^2\cdot10^{-2}\left\{\sum\frac{\frac{7k-3}{2l_1}\pi V\left[1{,}6\cdot10^8(3k-1)^4\frac{Y}{F}-(7k-3)^2(Vl_1)^2\right]}{\left[1{,}6\cdot10^8(3k-1)^4\frac{Y}{F}-(7k-3)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(7k-3)^8\left(\frac{Y}{F}\eta\right)^2}\times\right.$$
$$\times(7k-3)\sin\frac{7k-3}{2l_1}\pi Vt+$$
$$+\frac{\frac{3-5k}{2l_1}\pi V\left[1{,}6\cdot10^8(3k-1)^4\frac{Y}{F}-(3-5k)^2(Vl_1)^2\right]\cdot(3-5k)\sin\frac{3-5k}{2l_1}\pi Vt}{\left[1{,}6\cdot10^8(3k-1)^4\frac{Y}{F}-(3-5k)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(3k-1)^8\left(\frac{Y}{F}\eta\right)^2}\cdot$$
$$+3{,}6\left(\sum\frac{\frac{3k-1}{2l_1}\pi V\left[6{,}4\cdot10^7(3k-1)^2\frac{Y}{F}-(Vl_1)^2\right]}{\left[6{,}4\cdot10^7(3k-1)^2\frac{Y}{F}-(Vl_1)^2\right]^2+4\cdot10^{15}(3k-1)^4\left(\frac{Y}{F}\eta\right)^2}\cdot\frac{\sin\frac{3k-1}{2l_1}\pi Vt}{3k-1}+\right.$$
$$\left.\left.+\frac{\frac{1-k}{2l_1}\pi V\left[1{,}6\cdot10^8(3k-1)^4\frac{Y}{F}-(1-k)^2(Vl_1)^2\right]\cdot\frac{\sin\frac{1-k}{2l_1}\pi Vt}{(1-k)}}{\left[1{,}6\cdot10^8(3k-1)^4\frac{Y}{F}-(1-k)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(3k-1)^8\left(\frac{Y}{F}\eta\right)^2}\right\}\cdot\sin\frac{3k-1}{2l_1}\pi x\Bigg|;$$

$$\left|\mathrm{Re}\left\{y''_4\right\}\right|=\left|-\frac{2\cdot10^{-4}Ph_p^3}{F}\cdot\sum_{k=1}^{k^*}\left(\frac{1-k}{l_1}\right)^4cos1{,}3\cdot10^4\left(\frac{1-k}{l_1}\right)^2\sqrt{\frac{I}{F}}t+\right.$$
$$+PVl_1^2\cdot10^{-2}\left\{\sum\frac{\frac{7k-3}{2l_1}\pi V\left[1{,}6\cdot10^8(1-k)^4\frac{Y}{F}-(7k-3)^2(Vl_1)^2\right](7k-3)\sin\frac{7k-3}{2l_1}\pi Vt}{\left[1{,}6\cdot10^8(1-k)^4\frac{Y}{F}-(7k-3)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(1-k)^8\left(\frac{Y}{F}\eta\right)^2}+\right.$$
$$+3{,}6\left(\sum\frac{\frac{3k-1}{2l_1}\pi V\left[1{,}6\cdot10^8(1-k)^4\frac{Y}{F}-(3k-1)^2(Vl_1)^2\right]\cdot(3k-1)\sin\frac{3k-1}{2l_1}\pi Vt}{\left[1{,}6\cdot10^8(1-k)^4\frac{Y}{F}-(3k-1)^2(Vl_1)^2\right]^2+2{,}6\cdot10^{16}(1-k)^8\left(\frac{Y}{F}\eta\right)^2}+\right.$$
$$\left.\left.+\sum\frac{\frac{1-k}{2l_1}\pi V\left[6{,}4\cdot10^7(1-k)^2\frac{Y}{F}-(Vl_1)^2\right]}{\left[6{,}4\cdot10^7(1-k)^2\frac{Y}{F}-(Vl_1)^2\right]^2+4\cdot10^{15}(1-k)^8\left(\frac{Y}{F}\eta\right)^2}\cdot\frac{\sin\frac{1-k}{2l_1}\pi Vt}{(1-k)}\right)\right\}\cdot\sin\frac{1-k}{2l_1}\pi x\Bigg|.$$

When the rail is installed on a damping pad, the acceleration equations will take the form:

$$\left|\mathrm{Re}\left\{y_1''\right\}\right|=\left|1{,}6\cdot10^{-12}\frac{Ph_p^3}{YF}\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)\cdot Y+1{,}3\cdot10^{-4}j_{sp}\right]\times\right.$$
$$\cos\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]^{0.5}t+\frac{3\cdot P\cdot10^{-2}\cdot V}{l_1^2}\times$$
$$\times\left\{\sum\frac{-\frac{(7k-3)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times\right.$$
$$\times\sin\frac{(7k-3)}{2l_1}\cdot\pi Vt+$$
$$+\frac{-\frac{(3-5k)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3-5k}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3-5k}{2l_1}\cdot\pi Vt+$$
$$+\frac{-\frac{(3k-1)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{3k-1}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3k-1}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3k-1}{2l_1}\cdot\pi Vt+$$
$$\left.\left.+\frac{-\frac{(1-k)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{1-k}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times\sin\frac{1-k}{2l_1}\cdot\pi Vt\right\}\sin\frac{7k-3}{2l_1}\cdot\pi x\Bigg|,$$

$$\left|\mathrm{Re}\left\{y_2''\right\}\right|=\left|1{,}6\cdot10^{-12}\frac{Ph_p^3}{YF}\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)\cdot Y+1{,}3\cdot10^{-4}j_{sp}\right]^{0.5}\times\right.$$
$$\times\sin\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]^{0.5}t+\frac{3\cdot P\cdot10^{-2}\cdot V}{l_1^2}\times$$
$$\times\left\{\sum\frac{-\frac{(7k-3)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{7k-3}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times\right.$$
$$\times\sin\frac{7k-3}{2l_1}\cdot\pi Vt+$$
$$+\frac{-\frac{(3-5k)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3-5k}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3-5k}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3-5k}{2l_1}\cdot\pi Vt+$$
$$+\frac{-\frac{(3k-1)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3k-1}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3-5k}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3k-1}{2l_1}\cdot\pi Vt+$$
$$\left.\left.+\frac{-\frac{(1-k)^2}{2l_1}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{1-k}{2l_1}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\right]-\left(\frac{3-5k}{2l_1}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3-5k}{l_1}\right)^4\cdot\frac{Y}{F}\eta_1+1{,}3\cdot10^{-4}\frac{j_{sp}}{F}\eta_2\right]^2}\times\sin\frac{1-k}{2l_1}\cdot\pi Vt\right\}\sin\frac{3-5k}{2l_1}\cdot\pi x\Bigg|,$$

$$\left|\mathrm{Re}\left\{y_k^{\cdot}\right\}\right|=\left|1{,}6\cdot10^{-12}\frac{Ph_F^2}{YF}\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)\cdot Y+1{,}3\cdot10^{-4}j_{mp}\right]^{0{,}5}\times\right.$$
$$\times\sin\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]^{0{,}5}t+\frac{3\cdot P\cdot10^{-2}\cdot V}{l_i^2}\times$$
$$\times\left\{\sum\frac{-\frac{(7k-3)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{7k-3}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{7k-3}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times\right.$$
$$\times\sin\frac{7k-3}{2l_i}\cdot\pi Vt+$$
$$+\frac{-\frac{(3-5k)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{3-5k}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{7k-3}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{k-1}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3-5k}{2l_i}\cdot\pi Vt+$$
$$+\frac{-\frac{(3k-1)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{k-1}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{3k-1}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{k-1}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{3k-1}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3k-1}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3k-1}{2l_i}\cdot\pi Vt+$$
$$\left.\left.+\frac{-\frac{(1-k)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{3k-1}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{1-k}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{3k-1}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{1-k}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3k-1}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times\sin\frac{1-k}{2l_i}\cdot\pi Vt\right\}\sin\frac{3k-1}{2l_i}\cdot\pi x\right|,$$

$$\left|\mathrm{Re}\left\{y_k^{\cdot}\right\}\right|=\left|1{,}6\cdot10^{-12}\frac{Ph_F^2}{YF}\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)\cdot Y+1{,}3\cdot10^{-4}j_{mp}\right]^{0{,}5}\times\right.$$
$$\times\sin\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]^{0{,}5}t+\frac{3\cdot P\cdot10^{-2}\cdot V}{l_i^2}\times$$
$$\times\left\{\sum\frac{-\frac{(7k-3)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{7k-3}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{7k-3}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times\right.$$
$$\times\sin\frac{7k-3}{2l_i}\cdot\pi Vt+$$
$$+\frac{-\frac{(3-5k)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{3-5k}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{7k-3}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{k-1}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3-5k}{2l_i}\cdot\pi Vt+$$
$$+\frac{-\frac{(3k-1)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{k-1}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{3k-1}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{k-1}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{3k-1}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{3k-1}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times$$
$$\times\sin\frac{3k-1}{2l_i}\cdot\pi Vt+$$
$$\left.\left.+\frac{-\frac{(1-k)^2}{2l_i}\cdot\pi V\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{1-k}{2l_i}\right)^2\cdot(\pi V)^2\right\}}{\left\{\left[1{,}6\cdot10^8\left(\frac{1-k}{l_i}\right)^4\cdot\frac{Y}{F}+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\right]-\left(\frac{1-k}{2l_i}\right)^2\cdot(\pi V)^2\right\}^2+\left[1{,}6\cdot10^8\left(\frac{7k-3}{l_i}\right)^4\cdot\frac{Y}{F}\eta_i+1{,}3\cdot10^{-4}\frac{j_{mp}}{F}\eta_2\right]^2}\times\sin\frac{1-k}{2l_i}\cdot\pi Vt\right\}\sin\frac{1-k}{2l_i}\cdot\pi x\right|,$$

4. CONCLUSIONS

The obtained dependencies consider the structural, physical, and mechanical parameters of the 'wheel-rail' acoustic subsystem and the rail installation scheme. These dependencies allow performing an engineering calculation of the spectral composition of vibration and noise and justifying technical solutions for the required reduction in the levels of vibroacoustic characteristics.

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