High Frequency Vibrations in The Elements of the Rolling Stock on the Railway Bridges

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Abstract. The publication examines the emergence of high-frequency vibrations in the elements of the rolling stock and the railway track during the passage of vehicles on bridges. It is proposed to use a viscoelastic damper for oscillation of the superstructure at the place of intersection of the superstructure and transom I-beam supports. As a viscoelastic element, it is proposed to use an element of Kelvin-Voigt type. Installation of damper in the form of Jack or a damping device on a support, which is based on the span of the railway bridge, allows for the regulation of the speed of the underframe on the roadway, depending on the viscosity and elasticity of the damping device or jack, and the regulation of dynamic loads.

1. Introduction

At the present day, it is important to study the behavior of traditional constructions under various operating conditions of the rolling stock, including an increase in the frequency of dynamic effects and the superposition of effects from different loads and oscillations to achievement of the high-frequency range. High-frequency vibrations in the elements of the railway track and the rolling stock are more likely to appear during the traffic on artificial structures, such as bridges with different design diagrams and made from both reinforced concrete and steel. In such cases, the forced and free oscillation frequencies of different composite constructions of transport infrastructure are superimposed.

In general, the damping of oscillations and permanent way details, including rails, is more slowly on a bridge or an overbridge than the damping of the same details mounted on the roadbed. The failure mechanism of steel under high-frequency vibrations needs to be studied to ensure safe maintenance of the track.

Under high-frequency vibrations occurring in the system “transport facility – railway track” and affecting engineering structures [1, 2], the failure mechanisms differ from those under low-frequency vibrations [3–6]. Operating practices of assembled rails and sleepers, including on river crossings, has shown that the possible appearance of rail flaws can enter a defective stage and lead to an accident or track closure (if they are timely detected).

It is proposed to use a viscoelastic damper for oscillation of the superstructure at the place of intersection of the superstructure and transom I-beam supports. As a viscoelastic element, it is proposed to use an element of Kelvin-Voigt type, i.e. a construction with a parallel connection of an elastic and viscous element. Because of the viscous element, it is this construction (not the series
connection of an elastic and viscous element) which allows restoring the original size of the damper after the movement of the rolling stock on a bridge.

Depending on the speed and load on the span in on-line control, the viscosity parameters can be set by increasing pressure in the air modules or liquid viscosity in the damper.

Determination of the dynamic characteristics of the interaction of the locomotor and the roadway as an elastic element and determination of the time and place where the maximum interacting force has arisen, depending on the viscous and elastic characteristics of an elastic element, can solve the interaction problem of a damping device with a linear viscoelastic element of Kelvin-Voigt type according to the diagram shown in Figure 6, where the interaction of the locomotor and the superstructure is given as an example. The assumption that the damper laid on the support (e.g. in the form of Jack, see Figure 1) is a linear viscoelastic element, is theoretically valid for practical use.

![Diagram of damper with control parameters of the viscoelastic Kelvin-Voigt element.](image)

**Figure 1.** Damper diagram with control parameters of the viscoelastic Kelvin-Voigt element.

Consider a mechanical system consisting of two bodies. One of them is viscoelastic and damped under the second body; however, after the beginning of the contact with the second body, the first viscoelastic body is described (as an example of the system “underframe—superstructure”) by the system of differential equations:

\[
\begin{align*}
 m_1 (\ddot{z}_1 + \ddot{z}_3) + K (\dot{z}_1 - \dot{z}_2) + C (z_1 - z_2) &= 0; \\
m_2 (\ddot{z}_2 + \ddot{z}_3) + K (\dot{z}_2 - \dot{z}_1) + C (z_2 - z_1) &= 0,
\end{align*}
\]

where \( m_1 \) and \( m_2 \) are the mass of the vehicle and the superstructure respectively; \( z_1, z_2 \) are the coordinates of the vehicle and the superstructure about an upper point of the jack respectively; \( z_3 \) is the coordinate about the point of Jack relative to the inertial reference frame; \( K \) is the viscous resistance coefficient; \( C \) is the stiffness coefficient of the elastic element.

At the initial instant \( (t = 0) \) the first body is at rest, i.e. the equation (1) is considered under initial conditions:

\[
\begin{align*}
x(t = 0) &= 0; \ y(t = 0) = 0; \ x(t = 0) = 0; \ y(t = 0) = 0. 
\end{align*}
\]

As criteria characterizing the damping capabilities of Jack, the following can be adopted: the force acting on the trackform above the jack,

\[
I_1 = \max_{t\in[0,\infty]} P(t);
\]

the maximum displacement of the superstructure

\[
I_2 = \max_{t\in[0,\infty]} y(t);
\]

the acceleration of points in the superstructure
\[ I_2 = \max_{i \in \{0, m\}} \dot{y}(t). \]  

The values obtained from the formulas (3)-(5) should be compared to those required to ensure the safe maintenance of the superstructure.

The boundary conditions can be recorded as

\[ y(-1,0) = y(1,0) = \frac{\partial^2 y(-1,0)}{\partial x^2} = \frac{\partial^2 y(1,0)}{\partial x^2} = 0, \]  

where \( l \) is the half-length of the roadway between the seats (of a beam).

As initial conditions of the dynamical interaction of the bodies, the following can be adopted:

\[ y(x,0) = 0; \quad \frac{\partial y(x,0)}{\partial x} = 0. \]

The dependence of the local crushing on the contact force is determined in the solution of the contact problem using mechanical and geometrical parameters of the contacting bodies. The modified Hertz relation is most often used as the basic one:

\[ \alpha(t) = bP(t)q, \]

where \( b \) is the parameter characterizing the interaction model, which is defined by mechanical and geometrical properties of the contacting bodies; \( q \) is the contact area characteristic (\( q = 2/3 \) is for the initial contact at a single point; \( q = 1 - \frac{1}{2n+1} \) is for the tight initial contact; Goldsmith and some other researchers recommend this parameter should be determined experimentally).

Thus, the graphs indicate that the point displacement of the railway bridge is plotted on the basis of calculations. Figure 2 shows the dependencies of the normal displacement (deflection) under the contact area of the rolling stock with the permanent way plotted according to the Kelvin–Voigt model (curves 1-3) for different values of an elastic and viscous jack component. Curve 1 corresponds to the values where \( C = 103 \ N \cdot m, K = 106 \ N/s/m; \) curve 2 — \( C = 103 \ N/m, K = 103 \ N/s/m; \) curve 3 — \( C = 106 \ N/m, K = 103 \ N/s/m. \) Other interaction parameters have the following values: \( E = 2,1 \cdot 10^5 \ \text{MPa}; \) \( q = 2/3; \) \( m = 10 \ \text{t}; \) \( V_0 = 8 \ \text{m/s}; \) \( l = 2 \ \text{m}; \) \( r_0 = 0,1 \ \text{m}; \) profile type is double-T no. 40.

On the basis of the graphs shown in Figure 2, it may be concluded that the damper with a viscoelastic element installed on supports, ensures a longer reset time of the deflection of the superstructure to zero. The damper installed on supports allows selecting the viscosity and elasticity parameters for which the contact force remains practically intact after attaining its maximum and induces residual stresses.

![Figure 2. Time dependence of the normal displacement for different values of elastic and viscous characteristics of jack-damper.](image-url)
Based on the dynamic impact parameters for each value of elastic characteristic there is only one parameter value for viscosity (and conversely) where they work synchronously and quench the dynamic impact in the best way. In the design of actual hydraulic jack-dampers, it makes sense to use these elastic and viscous elements together selecting the viscosity and elasticity parameters, depending on the predicted characteristics of the dynamic impact. The effectiveness of the constructional decision depends on the time of the dynamical interaction, the frequency of dynamic load and reduction method of an original form of jack after the first effect.

Thus, installation of the damper in the form of jack or the damping device on supports, which is based on the span of the railway bridge, allows for the regulation of the speed of the rolling stock, depending on the viscosity and elasticity of the damping device or jack, and the regulation of dynamic loads.

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