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CONTACT DYNAMIC PHENOMENON CHARACTERISTIC TO LOCOMOTIVES

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Abstract: Smooth and safe guiding of wheel sets in curves and keeping them sable require a small tolerance for contact geometry at rail head level. Therefore, grinding track surface to maintain proper conditions for rolling is an essential issue for high speed lines. Railway vehicles lateral oscillation represents a major problem for high speed railways, which can be reduced by modifying vehicles Prud'homme limit and by improving track lateral resistance. Lateral movements cause passenger discomfort, and in some cases because of them the speed average can be reduced. In time, this could be the source for some trouble.

Key words: dynamic contact, wheel-rail dynamic, railway

1. INTRODUCTION

Nowadays, many high speed lines are in service all around the world. On some special high speed lines in Europe, a speed of 330 km/h is possible. In Germany, on some railway lines, traffic is combined: passenger high speed trains during the day and freight trains during night. No doubt, train high speed produce high dynamic forces. Contact forces produced by the powerful acceleration of motor wheels amplify surface alteration in wheel-rail contact area.

A possibility to solve this problem would be to reduce Prud'homme limit, defining allowed, repeated, lateral load, applied on track.

2. LATERAL FORCES AND WHEEL-RAIL DYNAMIC, TYPICAL FOR TWO WHEELS BOOGIES ENGINES

Lateral variable dynamic forces existing between the vehicle and the track can be produced by the rail and wheel profile, which are especially designed to control wheel lateral movements, and to improve wheel-rail contact. Lateral suspension and vehicle rolling features can amplify lateral forces, but this type of lateral oscillation can be managed by a special design and an efficient maintenance. Rolling features depend on suspension, permitted clearance between wheel, boogie and vehicle structure, and on motor wheel effect.

Track geometry represents a critical element. An efficient maintenance is easier to obtain if the vehicle has a high construction standard, and a big mass per length unity. Other rail or vehicle damages could lead to excessive vehicle swinging, gallop or vertical instability, all those amplify lateral forces. Under the pressure of these forces, rail can break elastically, causing temporary or permanent deformation, depending on lateral force size.

Permanent deformations are called origin distortion. If deformation number grows, because of frequent passing of poor maintained rolling stock, the rail shall progressively deteriorate and produce lateral oscillations to other vehicles. This is a vicious circle which leads to worn out or even destroyed track and vehicle suspensions. Lateral forces repeatedly worked on rail by the wheel is never higher than a certain *H* value, origin distortions do not sum up endless, and final distortion is set out in admissible limits.

Limiting value is *H* force value (1), *H* = lateral force, *P* [kN] = static wheel load. This proportion was first designed for ballast track with sleepers, without thermal variations. *H* force is considered rail breaking point where admissible standards of origin distortion are fulfilled, under the pressure of repeated lateral load, which vies with vertical load *P*. *Prud'homme* extended later his researches to consider thermal variation in the welded rail, and used a 0.85 multiplication factor. The final form of *Prud'homme* limit is shown at (2).

Research results conducted on BR 189 locomotives, on concrete sleepers, welded rail covered with ballast, with dynamic track stabilizer, on high speed lines did not determined important changes for *Prud'homme* formula, as it was demonstrated in fieldwork. In figure 1 is presented the second approach based on proportional external load of the wheel. Horizontal force *H* which acts in the centre of gravity, at c high from railhead, incurs resistance from H_1 and $(H - H_1)$ horizontal forces from rail level. Also, a wheel load variation appears like $R=H_c/e$, *e* is the distance between the line centers.

The higher wheel load is represented by *Q+R* (the dynamic wheel overload), and external wheel load is represented by *Q-R*. The proportional external load is calculated as $R/Q = H_c/Q.e$. A certain value of external load shall result when *H* reaches *Prud'homme* limit on normal gauge. This does not lead either to ride comfort, nor to derailments.

From a mathematical point of view, wheel oscillations in curves have an instable character. Lateral sliding friction of wheels in curves, where the gauge slightly extends compared to standard gauge, adds to oscillations that appear at wheel-rail contact level, where friction forces due to stick-slip phenomenon also interact. Practical researches demonstrated that lateral movement speed of the wheel in curves remains constant. Also, sliding friction forces are proportional in phase (3): If excitation is harmonic, then $\{f\} = \{\hat{f}\}.e^{i\omega t}$ and $\{q\} = \{\tilde{q}\}.e^{i\omega t}$.

If there is a column matrix $\{\hat{f}\}$ with real element which defines a excitation mode with "in phase" forces so that at any ω beat, q_j displacements should be all "in phase" between them, but not compulsory with $\{\tilde{q}\} = \{\hat{q}\}.e^{i\varphi}$ forces (φ represents the alteration of phase between forces and displacements). That means the $\{\hat{q}\}$ matrix has real elements.

The resonance appears when main frequency of input signal (when frequency leads to extreme values of power spectral density of excitation) is the same as the own frequency of oscillating system. This must be considered when setting methods to eliminate the resonance phenomenon. If input signal features a damped harmonic correlation, an enhancement of vibration system shall appear, acting as a maximum value of quadratic average acceleration when harmonic correlation frequency reaches the own frequency of oscillating system. In this case, power spectral density of input signal is as shown at (4).

For a dissipative system with dry friction (BR 182 electric locomotive suspension) the movement equation can be presented as in (5), $g(x)$- elastic force, R - positive constant. If $x' \prec 0 \prec x''$, equation solutions are presented at (7). If the mechanic system considered has neutral equilibrium, energy equation can be presented as at (8). In this case, speed is positive in the first semi-oscillation and negative in the second, after determining extreme elongations, periods can be calculated. If spectral densities of any w stable function " j " times differentiable are known, then quadratic average deviation of this function and of its derivative until *m* order are determined as at (11), $S_w(\nu)$ function is a symmetric function representing power spectral density of $p_T(\nu)$ function, which is stable, ergodic and determinable by *Fourier* transform. As the last condition is accomplished, the white noise appears, $x_0(t)$ *Fourier* integral is divergent.

Identifying $p(t)$ function with white noise means defining *white noise* as any $x(t)$ function with vanish identically *anticipated value*, representing by δ symbol *Dirac* distribution. $G(t)$ *Green* specific function represents *white noise* intensity. Considering any X variable having only real values and $f_x(x)$ probability density, then α_1 is called *x anticipated value* of *x*, noted m_x if $\alpha_r = \int_{-\infty}^{\infty} x^r . f_x(x) dx$ ($r \in N$). In this case, $S_{x_0}(\nu)$ function is power spectral density of $p(t)$ function. If *anticipated value* for any signal is vanish identically, then the function that describes input signal has *retarded potential*. Generally speaking, correlation function and power spectral density of any stable $x_0(t)$ function diminish the spectral band and power spectral density of different values considered outputs of a oscillating mechanic system. Also, $S_{x_0}(\nu)$ and $S_{\ddot{x}_0}(\nu)$ functions represent power spectral density of input, and quadratic average deviation of any stable function " j " times differentiable, previously determined. If any $x_0(t)$ function has an exponential correlation, quadratic averages also develop in case of damped harmonic correlation, changing the variable.

If the correlation function is a linear combination between exponential correlation and damped harmonic correlation, an enhancement appears in vibrations system in quadratic averages of the answer. It shall act as a maximum value of quadratic average acceleration when harmonic correlation frequency is closed to own frequency of oscillating system.

A free oscillating system was considered as analytic sample in which dissipative force is proportional with any value of $\dot{x}$ oscillation speed, like (12). For this oscillating system, input signal is represented by any normal process having an exponential correlation, consequently movement differential equation is adapted as shown in (13). If the oscillating system can be described by the equation: $x(t) = A.x_0(t) \Rightarrow x_0(t) = A^{-1}.x(t)$, $x_0(t)$ is the external signal acting on the system, then $x(t)$ function represents the answer that the mechanic system gives for external action, and A parameter represents all the elements composing considered oscillating mechanic system. If we consider A^{-1} a linear differential operator like (14), then A exists, it is linear, and operator linearization methods will be used to determine linear mechanic system features. These methods describe movement equation (system oscillations).

To determine oscillations from a locomotive such as BR 189 ES 64 F4 during its service, it shall be considered that the locomotive has, beside its main advancing movement, other parasite movements tending to limit vehicle's riding. These parasite oscillations are the result of external forces acting on motor vehicle, mainly caused by the irregularities and imperfections of the track, especially in areas highly exposed to efforts, as joints and frogs. To determine the action that sinusoidal deviation has on track in vertical plane, external forces resultant and static moment related to an axis passing through vehicle's centre of gravity are first determined.

As the wheel-rail contact point moves (wheel centre, suspension points of springs on a harmonic curve), phenomenon that leads to wheel alternative rising and getting down, the vehicle's shell receives through suspension a disturbing force which can be decomposed as a *Fourier series*. Its fundamental harmonic is like (15) as it has the biggest amplitude equal to $h/2$ and wavelength is equal to rail length.

Another opinion is to lower the vehicles' centre of gravity. For passenger cars, a lower shell is possible, also for freight cars. If research organization coordinated field testing or computer simulations to set lateral rigidity of standard gauge railways more precisely, it would be an important help.

3. EQUATIONS AND NUMERICAL COMPUTATION

$$H = 10 + 0{,}33\, P,\ \text{H [kN]} \tag{1}$$

$$H = 0{,}85(10 + 0{,}33\, P). \tag{2}$$

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + \frac{1}{\omega}[H]\{\dot{q}\} + [K]\{q\} = \{f\}. \tag{3}$$

$$S_{x_0}(\nu) = \frac{\sigma_{x_0}^2}{\pi}\frac{\alpha_1\left(\alpha_1^2 + \beta_1^2 + \nu^2\right)}{\nu^4 + 2(\alpha_1^2 - \beta_1^2)\nu^2 + \left(\alpha_1^2 + \beta_1^2\right)},\ \text{for } |\nu| \prec \nu_1. \tag{4}$$

$$\ddot{x} + R\,\mathrm{sgn}\,\dot{x} + g(x) = 0, \tag{5}$$

$$\text{Also, } \mathrm{sgn}\,\dot{x} = \frac{|\dot{x}|}{\dot{x}} = \begin{cases} 1; if : \dot{x} \succ 0 \\ -1; if : \dot{x} \prec 0 \end{cases} \tag{6}$$

$$|g(x)| = R \ \text{ and if } \begin{cases} x \in [x'; x''] \\ \dot{x} = 0 \end{cases}, \tag{7}$$

$$\frac{v^2}{2} + R.x\,\mathrm{sgn}\,v + G(x) = C,\ \text{then initial conditions:} \tag{8}$$

$$x = x_1 \prec x',\ v = 0 \ \text{ and} \tag{9}$$

$$t = 0 \Rightarrow C = R.x_1 + G(x_1) \Rightarrow v = \sqrt{2[G(x_1) - G(x) + R(x_1 - x)]}. \tag{10}$$

$$\sigma_{w^{(j)}}^2 = 2\int_0^\infty S_{w^{(j)}}(\nu)d\nu = 2\int_0^\infty \nu^{2j} S_w(\nu)d\nu, \tag{11}$$

$$P = k\,\mathrm{sgn}\,\dot{x}|\dot{x}|^i. \tag{12}$$

$$\ddot{x} + A\,\mathrm{sgn}\,\dot{x}|\dot{x}|^i + \omega^2 x = -\ddot{x}_0,\ A = \frac{k}{m}. \tag{13}$$

$$A^{-1} = \sum_{i=0}^{n} a_i(t)\frac{d^i}{dt^i} \tag{14}$$

$$z_s = \frac{h}{2}\sin\frac{2.\pi}{l_s}x\,, \tag{15}$$

4. CHARTS AND DRAWINGS

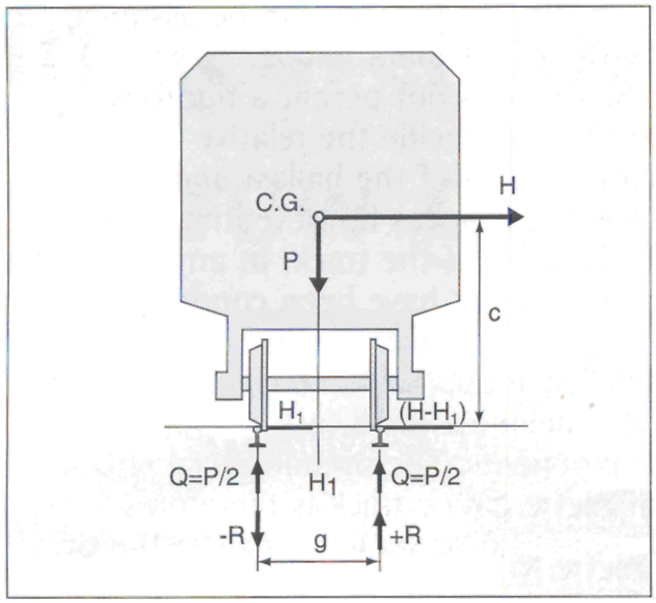

Figure 1. Vertical plane of dynamic forces

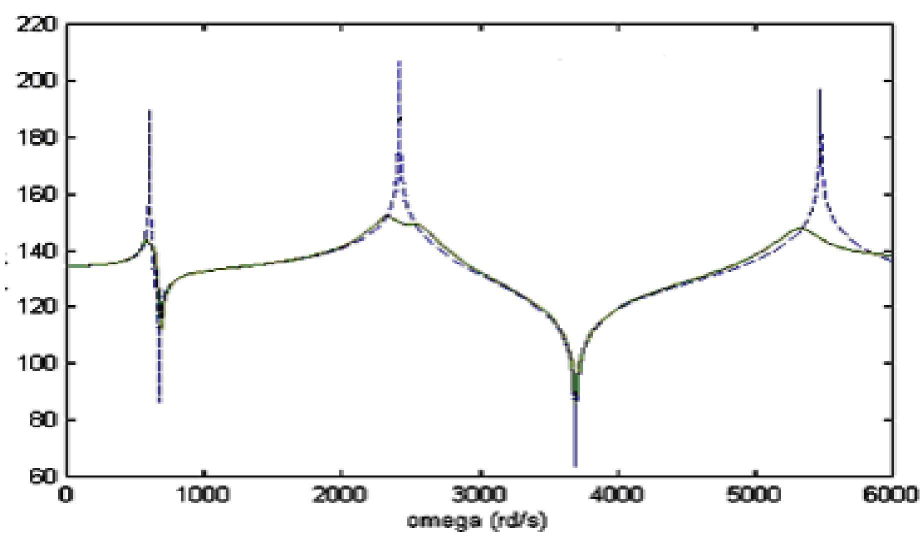

Figure 2. Oscillating frequencies in vertical plane for a two wheels boogies motor vehicle

5. CONCLUSIONS

Railway traffic can generate strong ground shakings, especially freight trains heavily loaded. In some cases, high speed trains generate higher ground shakings. In some areas, with alluvial soil, temporary speed restrictions have been imposed, to reduce shakings' level. Not very often, shakings cause buildings damages. Mostly, only superficial cracks appear on street fronts, external and internal walls etc. But these lower the price of the building.

The big problem seems to be the discomfort that residents feel. The importance of shakings caused by the railway traffic will grow more in the next future, as railway traffic gets every day deeper into the center of town, at every hour of the day and night.

It was demonstrated that high speed trains can reach a higher speed than *Rayleigh* wave, reducing the wave propagation speed in the ground, depending on the embankment. Very strong shakings are generated in the ground. Train speed is also close to critical speed, which appears because of the interaction between the embankment and the ground. It is possible that the movement would be so big as to threat the embankment stability.

Environmental problems caused by freight and passenger trains are, probably, more important than those caused by high speed trains. Consequently, higher frequency shakings than normal should be considered in geo-technology, as human being senses vibrations with up to 80 Hz frequency.

Usually, only up to 20 Hz frequencies are studied by geo-technology. Many of the shaking problems are made of several factors: a source emits energy in the environment which transmits the energy to an object, a receiver. From a geo-technical point of view, the train, the rails, the ballast bed, the sleepers and the embankment represent the source. The ground and what is on the ground is the environment, on which the embankment is laid. The object, the receiver, is mostly a building or more.

It is possible that speed limitation applied to combined traffic railways would be stopped, by creating conditions to grow the multiplication factor to more than 0.8. This would be possible by a higher lateral strength of track. For example, crossing ribs could be monolithic built-in with concrete sleepers to create more lateral resistance of ballast.

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