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Dissipation Effect in the Hunting Motion Stability of Wheel Set with Elastic Joints

The axle hunting is a coupled lateral and yaw self oscillatory motion which is largely determined by wheel–rail contact geometry. The stability of this motion is an important dynamic problem that determines the maximum operating speed of railway vehicle. To improve the stability performances, without increasing the rail-wheel interaction forces above safety limits, elastic joints and dissipative devices are used to connect the wheelset to the bogy frame. In this paper is studied the influence of passive linear and non-linear dissipative horizontal forces on the hunting motion stability of a wheelset with elastic joints.

Keywords: *Hunting motion, nonlinear dissipation, critical speed*

1. Introduction

The hunting motion occurring in case of the railway vehicles is a consequence of the reversed conic shape of the wheel rolling surfaces [1, 2]. This produces a difference in the rolling radii of the two wheels when the wheelset is displaced to one side. Since the wheels are rigidly connected together through the axle, they and must spin at the same rate. Therefore, the forward velocity of the first wheel is larger than the forward velocity of the second wheel. This causes a rotation of the axle toward the center of the track, with the yaw angle continuing to increase until the axle center moves back to the middle of the track. This motion continues, with the axle oscillating from side to side in coupled lateral and yaw motion referred to as axle hunting. Below a certain vehicle riding speed, called the critical speed, the hunting motion appears as a damped sinusoidal oscillation along the track centerline. Above this critical speed, the motion becomes unstable and the displacement increases until the play between the wheel flanges and track is consumed. As the speed increases, the wheels- track contact force becomes large enough to cause rail damage, discomfort and eventually can lead to derailment. Particularly, for the high-speed passenger trains, the problem of achieving high-speed operation without the hunting instability has always been of interest to vehicle designers [3].

The effect of primary suspension and the effect of lateral linear stiffness on the hunting stability of a rail wheelset have been investigated in [4, 5]. Passive stabilization of the amplitude of self-oscillations or elimination of self-oscillations by appropriately selecting the parameters of the tread contour has been studied in [6, 7].

In this paper is analyzed the effect of passive control of hunting motion stabilization by using hydraulic shock absorbers with linear and nonlinear damping characteristics, working in parallel with the springs of a wheelset with elastic joints [8,9]. The nonlinearity type of damping characteristic, presented in this paper, has a similar effect on mitigation of hunting motion as the semi-active control strategies implemented with magnetorheological dampers [10].

2. Analytical models of wheelset hunting motion in linear case

The wheelset is modeled by an oscillating system with two degrees of freedom. The hunting motion is studied with respect to an inertial system of reference which moves with a constant velocity along the track centerline. In figure 1 is shown the physical model of the wheelset with elastic joints and dampers in parallel connections.

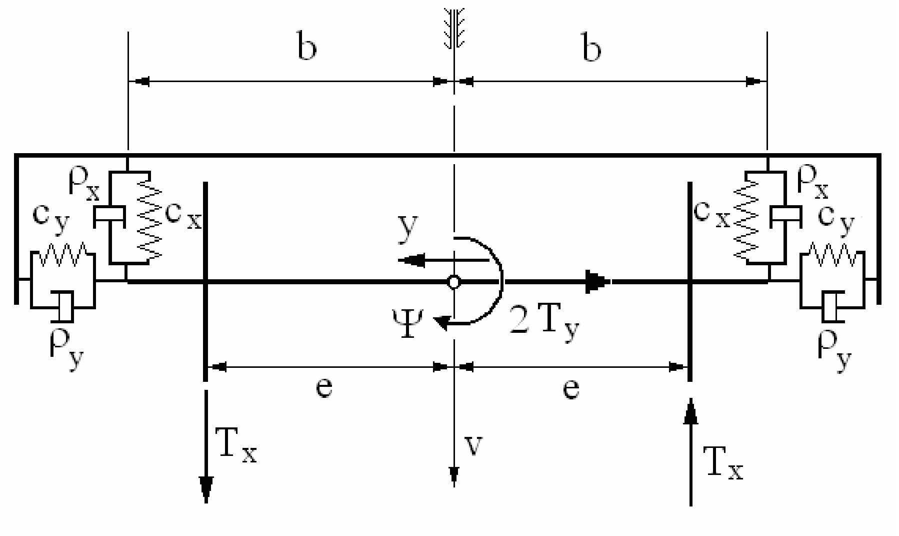

Figure 1. Mechanical model of a wheelset with elastic joints and linear viscous damping

In this case, the linear case, as is shown in figure 1, the movement equations are given by (1)

$$\begin{aligned} & m_0\ddot{y}+\left(2\rho_y+\frac{2\chi Q}{v}\right)\dot{y}+2c_y y-2\chi Q\Psi=0 \\ & I_{0z}\ddot{\Psi}+\left(2\rho_x+2\chi Q\frac{e^2}{v}\right)\dot{\Psi}+2bc_x\Psi+2e\chi Q\frac{\gamma}{r}y=0 \end{aligned} \qquad (1)$$

The simulation parameters are:

$E=210\ kN/mm^2$	Elasticity modulus
$\vartheta=0,3$	Poisson coefficient
Q=7,5 t	Axle load
C_{11}, C_{22}, C_{23}	Kalker's coefficients
$\chi_x=\chi_y=100$	quasi-slipping coefficients
$\chi_s=1,7$	
$k_x=9\cdot10^5\ N/m$,	Elasticity coefficients
$k_y=5,43\cdot10^5\ N/m$	

The initial conditions in simulations are: $y_1=1\ mm,\ \varphi_1=0,5$,

In figure 2 is shown the displacement of hunting motion of the axle in time and in phases plane for V=25 m/s.

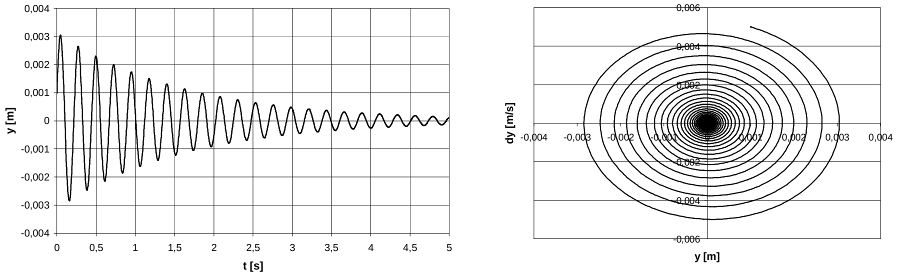

Figure 2. The hunting motion displacement in time and in plan phases before the critical speed

This situation is corresponding to a situation before the critical speed of the hunting movement of the railway axle.

In figure 3 is shown the displacement of hunting motion of the axle in time and in phases plane for V=40 m/s, it is corresponding to a situation after the critical speed of the hunting movement of the railway axle.[1,2]

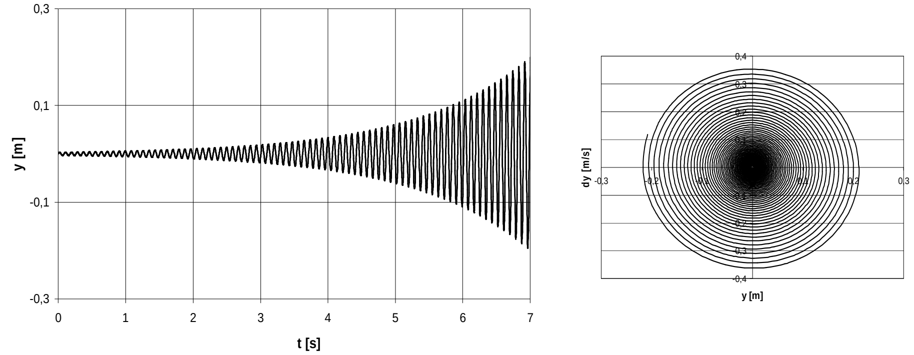

Figure 3. The hunting motion displacement in time and in plan phases after the critical speed

In figure 4 is shown the displacement of hunting motion of the axle in time and in phases plane for V=33.5 m/s, it is corresponding to critical speed of the hunting movement of the railway axle, in the linear case.

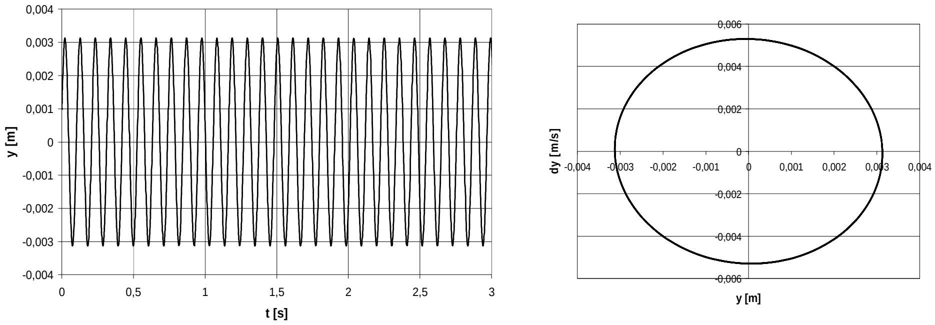

Figure 4. The hunting motion displacement in time and in plan phases at the critical speed

3. Nonlinear dissipation influence in the system

In theoretical cases of nonlinear dissipation, the damping coefficient depends on the velocity but the displacement of piston to. The mechanical model of elastic joint axle movement in nonlinear case is shown in figure 5

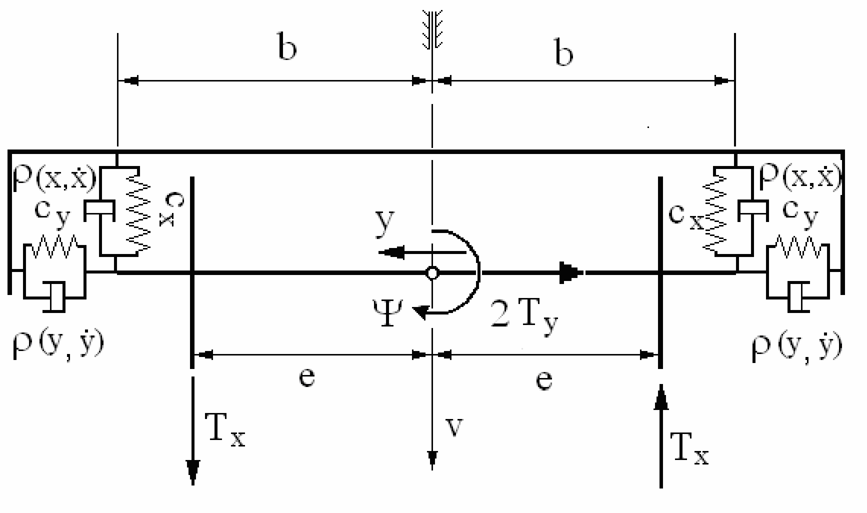

Figure 5. Mechanical model for the axle movement in nonlinear case

The movement equations (1) become:

$$\begin{aligned} & m_0\ddot{y} + F_{y,\dot{y}} + \left(\frac{2\chi Q}{v}\right)\dot{y} + 2c_y y - 2\chi Q\Psi = 0 \\ & I_{0z}\ddot{\Psi} + F_{\Psi,\dot{\Psi}} + \left(2\chi Q\frac{e^2}{v}\right)\dot{\Psi} + 2bc_x\Psi + 2e\chi Q\frac{\gamma}{r}y = 0 \end{aligned} \qquad (2)$$

The damping characteristic is given by (3):

$$F_{x,\dot{x}} = c\dot{x} + a|x|^{\alpha}[1-\operatorname{sgn}(x\dot{x})]\cdot|\dot{x}|^{\beta}\operatorname{sgn}(\dot{x}) \qquad (3)$$

The VZN dumpers provide this type of dissipative characteristic, is a Romanian invention by PhD. eng. Adrian Niculescu [11...13], international brevet: *Automotive self-adjustable damper with a self-correcting dissipation characteristic EP1190184*.

In figure 6 are given the time history and the dissipation characteristic of a nonlinear dumper which satisfying relation (3), in following condition:

$$\alpha = 3,\ \beta = 2,\ a = 5 \cdot 10^{11},\ \rho = 400 \text{ Ns/m},\ f = 5 \text{ Hz},\ X_0 = 5 \text{ mm.}$$

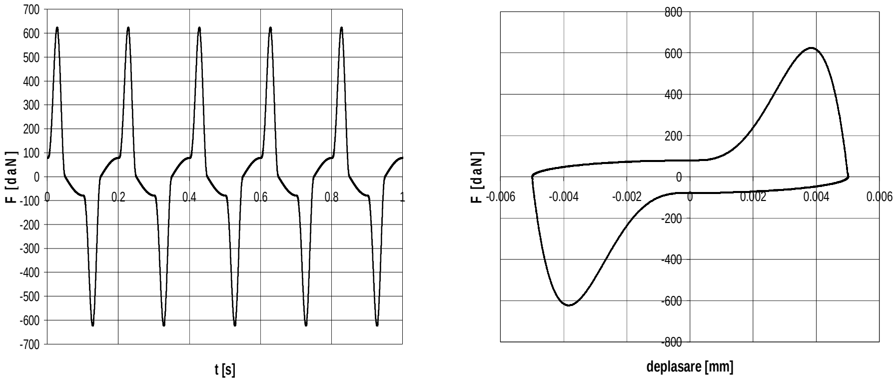

Figure 6. F(t) and F(d) characteristic for proposed dumper

In figure 7 is given (in time and in fazes plane), the transversal response of the axle for V=25 m/s.

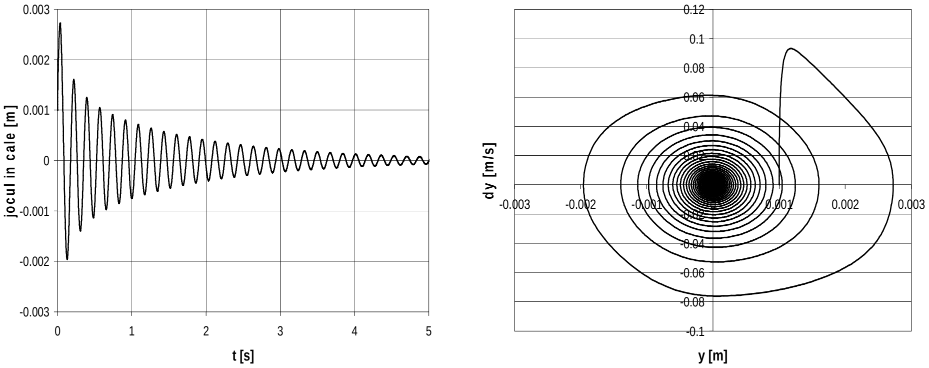

Figure 7. The hunting motion displacement of the axle for V=25 m/s

In figure 8 is given (in time and in fazes plane), the transversal response of the axle for V=50 m/s.

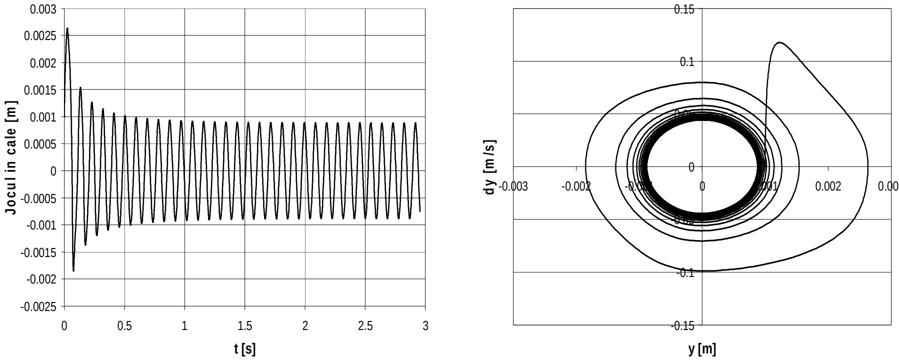

Figure 8. The hunting motion displacement of the axle for V=50 m/s

In figure 9 is given (in time and in fazes plane), the transversal response of the axle for V=300 m/s.

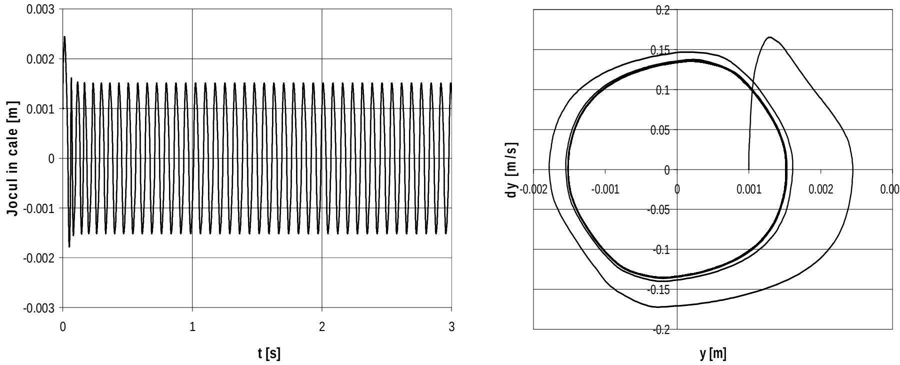

Figure 9. The hunting motion displacement of the axle for V=300 m/s

As is shown in preview figures 7-9, this type of nonlinear damping is very useful to eliminate the transversal movement instability.

In figure 10 two devices which provide a nonlinear dissipation given by relation (3) was designed. These devices are hydraulic, use the metal bellows and not require sealing.

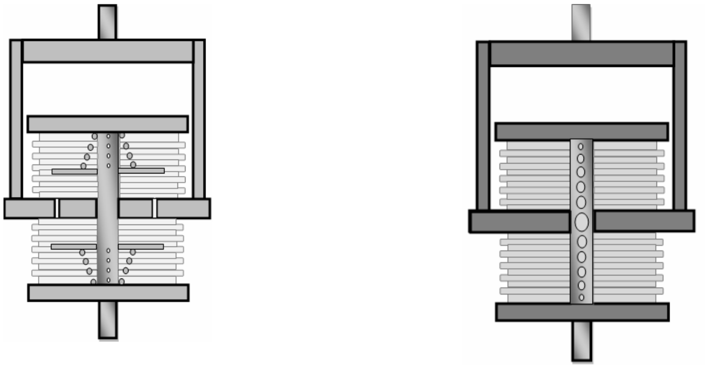

Figure 10. Hydraulic nonlinear devices with metal bellows

In figure 11 is given a comparison in transversal displacement between the two situation of elastic joint axle hunting movement with linear and nonlinear dissipation. The simulation in both studied case where done in identical conditions for different travel velocity.

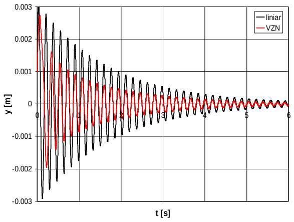

Figure 11a. Comparison in transversal displacement between linear and nonlinear dissipation cases for V=25 m/s

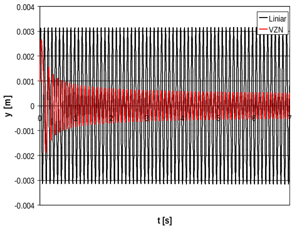

Figure 11b. Comparison in transversal displacement between linear and nonlinear dissipation cases for, V=33.5 m/s

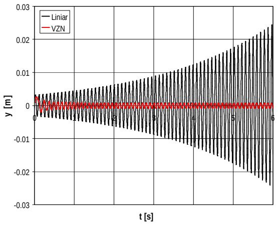

Figure 11c. Comparison in transversal displacement between linear and nonlinear dissipation cases for, V=40 m/s

4. Conclusions

1. The hunting motions of the axles with horizontal elastic joints of the railway vehicles bogies is caused by the movement to the different rolling ray of the same axle because of irregular profiles of wheels and limits the top speed of the railway vehicles.

2. The hunting mouvement of the vehicle axle has a strong dynamic instability for higher speed than crithical speed of the hunting motion and that fact coerse the maximum train speed.
3. Using the linear dissipation devices in the both principal directions in horizontal plane, the hunting motion critical speed can be significantly increase, but the transversal forces given by the supplementary dissipation can grow over the derailment limit. In this conditions, the critical speed of hunting motion can be increase just with 50-70 %, after that the axle rolling can be unsaved because the increasing of transversal forces.
4. A significant increasing of the hunting motion critical speed is possible without a major increase of transversal forces, by using nonlinear dissipation devices in both principal directions in horizontal plane of axle joints.
5. By using nonlinear special dissipative devices type VZN, in the axles joints, the instability of the hunting movement can be eliminate.

Acknowledgments

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