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The Influence of the Wheel Conicity and the Creep Force Coefficients to the Hunting Motion Stability of a Bogie with Independently Rotating Wheelsets

The hunting motion of railway vehicles 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, depends of the railway vehicles speed and determines the maximum operating speed of the vehicles. 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 bogie frame. In this paper is studied the influence of the wheel conicity and the creep force coefficients to the hunting motion stability of a dynamical system with 10 DOF representing a bogie with independently rotating wheelsets

Keywords: *Hunting motion, critical speed, bogie, creep, conicity*

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. 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. The influence of wheel conicity to the critical speed of hunting motion of a wheelset with elastic joints was studied in [3, 4].

The effect of primary suspension and the effect of linear stiffness on the hunting stability of a rail wheelset have been investigated in [5, 6]. 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 [7, 8]. An analytical investigation of Hopf bifurcation and hunting behavior of a rail wheelset with nonlinear primary yaw dampers and wheel-rail contact forces is presented in [9]. The influence of linear and nonlinear dissipation in horizontal plane of a wheelset with elastic joints is also studied in [10,12] and the semi-active control strategies implemented with magnetorheological dampers [13].

In this paper is analyzed the influence of the wheel conicity and the creep force coefficients to the hunting motion stability of a dynamical system with 10 DOF representing a bogie with independently rotating wheelsets.

2. Analytical models of the bogie

In figure 1 is shown the physical model of the bogie with independently rotating wheelsets.

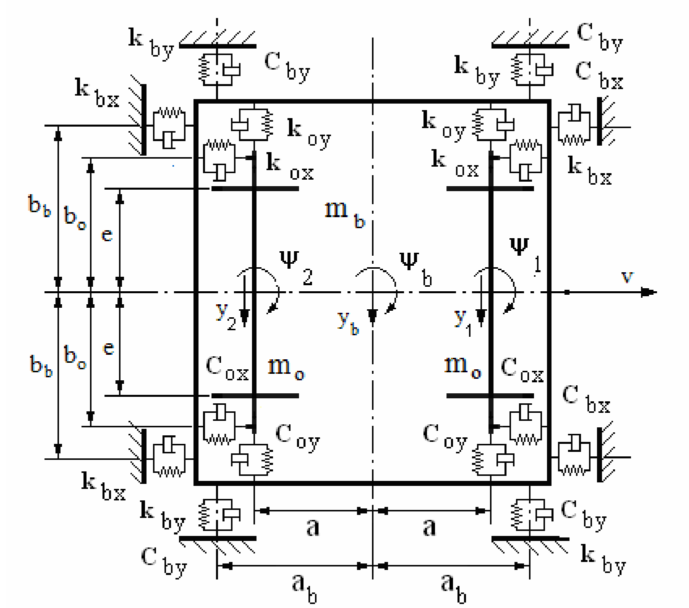

Figure 1. The model of a bogie with independently rotating wheelsets

The bogie is modeled by an oscillating system with ten 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. The elastic and damping characteristics of the mechanical model are linear. In this case, as is shown in figure 1, the movement equations are given by the following system of equations:

$$\begin{aligned}
&m_b\ddot{y}_b+4C_{oy}\left[\dot{y}_b-\left(\frac{\dot{y}_1+\dot{y}_2}{2}\right)\right]+4C_{by}\dot{y}_b+4K_{oy}\left[y_b-\left(\frac{y_1+y_2}{2}\right)\right]+4K_{by}y_b=0\\
&I_{bz}\ddot{\psi}_b+4C_{ox}b_o^2\left[\dot{\psi}_b-\left(\frac{\dot{\psi}_1+\dot{\psi}_2}{2}\right)\right]+4C_{bx}b_b\dot{\psi}_b+4K_{ox}b_o^2\left[\psi_b-\left(\frac{\psi_1+\psi_2}{2}\right)\right]+\\
&\qquad+4K_{bx}b_b\psi_b+4C_{oy}a\left[a\dot{\psi}_b-\left(\frac{\dot{y}_1-\dot{y}_2}{2}\right)\right]+4C_{by}a_b^2\dot{\psi}_b+\\
&\qquad+4K_{oy}a\left[a\psi_b-\left(\frac{y_1-y_2}{2}\right)\right]++4C_{by}a_b^2\psi_b=0\\
&m_o\ddot{y}_1-2C_{oy}(\dot{y}_b-a_b\dot{\psi}_b-\dot{y}_1)-2K_{oy}(y_b-a_b\psi_b-y_1)+\chi\mathrm{Q}\left(\frac{\dot{y}_1}{V}-\psi_1\right)=0\\
&I_{oz}\ddot{\psi}_1+2C_{ox}b_o^2(\dot{\psi}_b-\dot{\psi}_1)+2K_{ox}b_o^2(\psi_b-\psi_1)+\chi\mathrm{Q}e\left(\frac{\gamma}{r}y_1+\frac{e}{V}\dot{\psi}_1\right)=0\\
&m_o\ddot{y}_2-2C_{oy}(\dot{y}_b-a_b\dot{\psi}_b-\dot{y}_2)-2K_{oy}(y_b-a_b\psi_b-y_2)+\chi\mathrm{Q}\left(\frac{\dot{y}_2}{V}-\psi_2\right)=0\\
&I_{oz}\ddot{\psi}_2+2C_{ox}b_o^2(\dot{\psi}_b-\dot{\psi}_2)+2K_{ox}b_o^2(\psi_b-\psi_2)+\chi\mathrm{Q}e\left(\frac{\gamma}{r}y_2+\frac{e}{V}\dot{\psi}_2\right)=0
\end{aligned}\tag{1}$$

3. Simulation parameters and results

The simulation parameters are:

m_o=1500 kg, Ioz=840 Nm2 m_b=3000 kg, Ibz=500 Nm2	Inertial parameters
χ_x=χ_y=400, [50…400]	Creep coefficient in horizontal plane
Q=7,5 t	Axle load
b=1 m, b_b=1.25 m, a=1.4 m a_b=1.5 m, e=0.75 m, r=0.46 m, γ=0.13	Geometric parameters
$k_{ox}=9\cdot10^5$ N/m, $k_{oy}=5.43\cdot10^5$ N/m	Elasticity coefficients

$k_{bx}=2{\cdot}10^6$ N/m, $k_{by}=2{\cdot}10^6$ N/m	
$C_{ox}= C_{oy}=20$ and 50 kNs/m $C_{bx}=C_{by}=20$ kNs/m	Damping coefficients
$y_b=2$ mm, $y_1=2$ mm, $y_2=1$ mm	Initial conditions

In figure 2 is shown the displacement of hunting motion of the bogie in time and in phases plane before the critical speed for $C_{ox}= C_{oy}=20$ kNs/m.

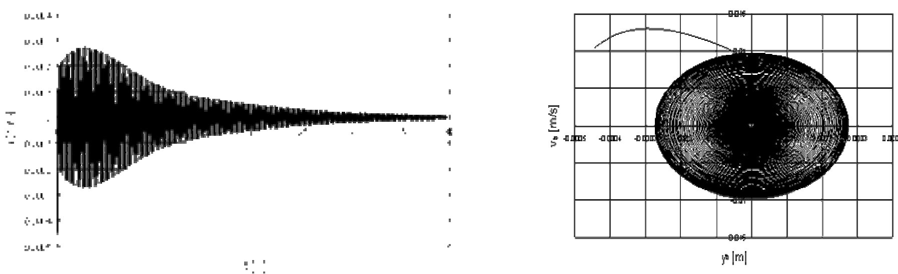

Figure 2. The hunting motion displacement of the bogie in time and in plan phases before the critical speed

In figure 3 is shown the displacement of hunting motion of the bogie in time and in phases plane, after the critical speed $C_{ox}= C_{oy}=20$ kNs/m

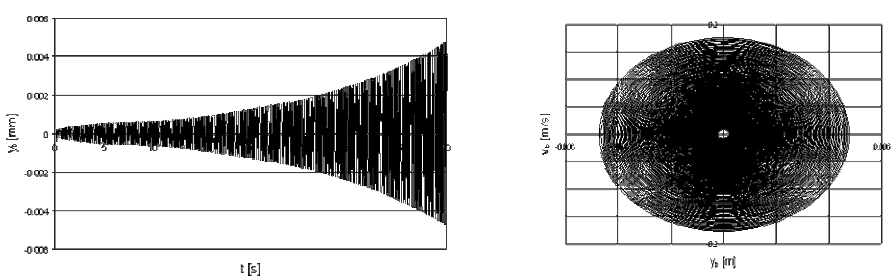

Figure 3. The hunting motion displacement of the bogie in time and in plan phases after the critical speed

In figure 4 is shown the displacement of hunting motion of the bogie in time and in phases plane at critical speed for $C_{ox}= C_{oy}=20$ kNs/m

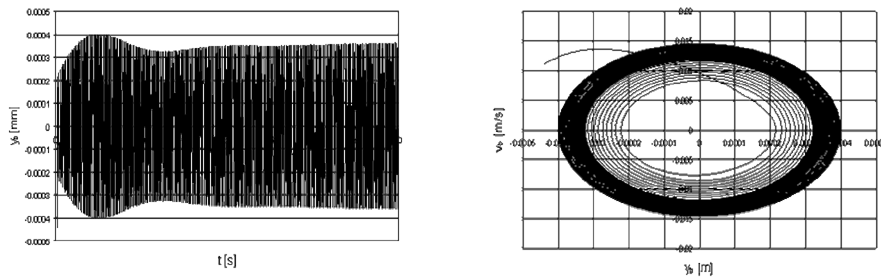

Figure 4. The hunting motion displacement of the bogie in time and in plan phases at the critical speed

In figures 5-7 are presented the same tree previous situations befor, after and at critical speed of hunting motion, for a bigger value of dissipations in horizontal plane between wheelsets and bogie $C_{ox}= C_{oy}= 50$ kNs/m.

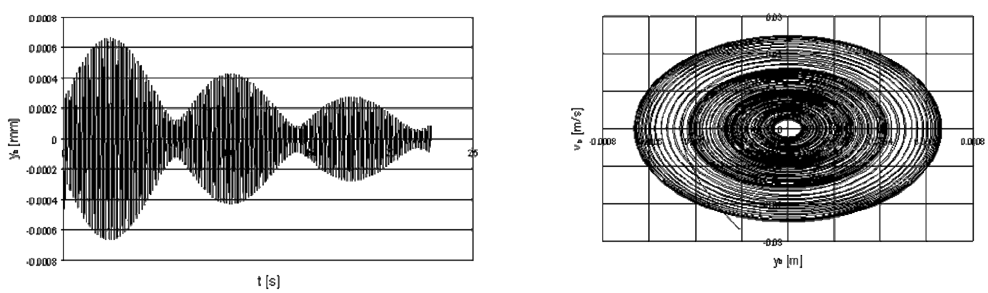

Figure 5. The hunting motion displacement of the bogie in time and in plan phases before the critical speed

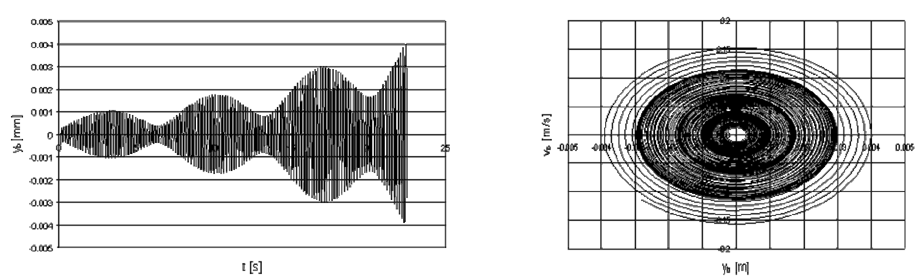

Figure 6. The hunting motion displacement of the bogie in time and in plan phases after the critical speed

In the following figure is shown the displacement of hunting motion of the bogie in time and in phases plane at critical speed

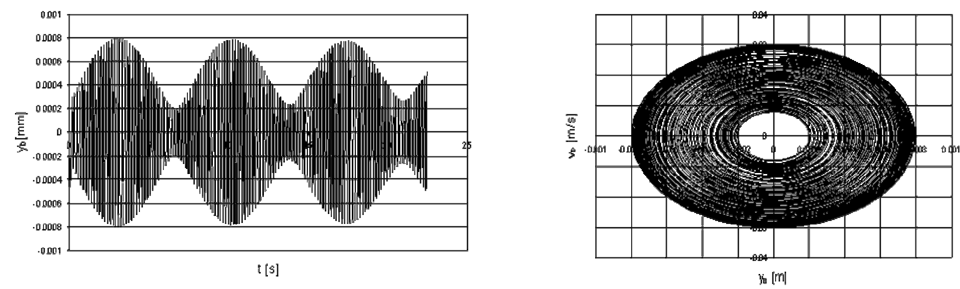

Figure 7. The hunting motion displacement of the bogie in time and in plan phases at the critical speed

In figures 8 and 9 are prezented of the wheel conicity and the creep force coefficients to the hunting motion stability of the considered dynamical system. As is shown in these figures the stability of hunting motion of the bogie with independently rotating wheelsets decrease with increasing of these coefficients.

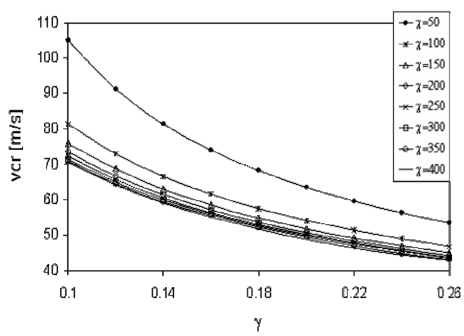

Figure 8. The critical speed of hunting motion versus wheel conicity

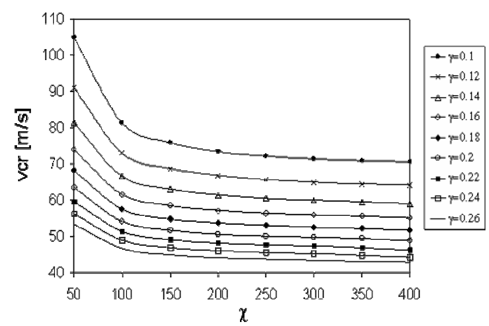

Figure 9. The critical speed of hunting motion versus lateral creep force coefficient

4. Conclusions

1. The hunting motion of the bogie with independently rotating wheelsets 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. Both instability of bogie and wheelset hunting motions of a bogie with independently rotating wheelsets occur in the dynamical system at the same time

3. The hunting movement of the vehicle bogie and axle has a strong dynamic instability for higher speed than critical speed of the hunting motion and that fact coerce the maximum train speed.
4. Using the linear dissipation devices in the both principal directions in horizontal plane, the hunting motion critical speed can be increase.
5. The increasing of the dissipation coefficients in horizontal plane between bogie and wheelsets increasing the hunting motion critical speed but producing a movement coupling between the two vibrating masses.
6. The increasing of the wheel conicity coefficient by usage or by other phenomenon inducing in the system a decreasing of the hunting motion critical speed.
7. The increasing of the lateral creep force coefficient by environmental conditions or by other phenomenon induce in the system a decreasing of the hunting motion critical speed

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