A Research on the Effects of Braking Torque on Dynamic Load of Tractor Semi-trailer on a Straight Road with the Friction Factor

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The paper presents the research results on the dynamic load of tractor semi-trailer on a straight road with the maximum longitudinal friction factor $\Phi_{xmax} = 0.8$ at speed $V0 = [60, 80]km/h$, being braked with 6 different braking torques. The method of structural separation of a multi-body system is used to build a 3D dynamic model of the tractor semi-trailer and the Newton-Euler equation is used to set up the system of dynamic equations of tractor semi-trailer. MATLAB-Simulink software is used to examine the effects of braking torque on dynamic load of the tractor semi-trailer. The results showed that, the wheel force of axle 1 is increased by 200%, but the wheel force of axle 3 is reduced about 13.3%, and the wheel force of axle 6 is reduced about 21.6%.The dynamic load factor of axle 1 is increased by 200%, but the dynamic load factor of axle 3 is reduced about 9%, and the dynamic load factor of axle 6 is reduced about 22%.

Keywords: Braking torque, Dynamic load factor, Wheel force, Tractor semi-trailer.

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1 Introduction

The braking torque greatly affects the braking efficiency, dynamic load, vibration and stability of tractor semi-trailer. The maximum dynamic load acting on the tractor semi-trailer is assessed by the maximum dynamic load factor ($k_{dij,max}$). The maximum dynamic load factor of the tractor semi-trailer is determined by the following formula [1, 5, 6]:

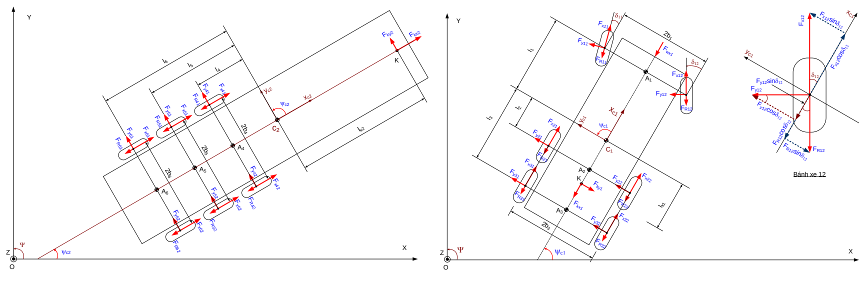
$$k_{dij,max} = \frac{F_{zij}}{F_{Gij}} = 1 + \frac{F_{CLij,max}}{F_{Gij}} \; ; \quad k_{dij,max} \le 2.5 \tag{1}$$

$$F_{zij} = \begin{cases} F_{CLij} + F_{Gij} & if \quad h_{ij} - \left[\xi_{Aij} - f_{ij}^{t}\right] \ge 0 \\ 0 & if \quad h_{ij} - \left[\xi_{Aij} - f_{ij}^{t}\right] < 0 \end{cases} \tag{2}$$

$$F_{CLij} = \begin{cases} C_{Lij}\left(h_{ij} - \xi_{Aij}\right) & if \quad h_{ij} - \left[\xi_{Aij} - f_{ij}^{t}\right] \ge 0 \\ 0 & if \quad h_{ij} - \left[\xi_{Aij} - f_{ij}^{t}\right] < 0 \end{cases} \tag{3}$$

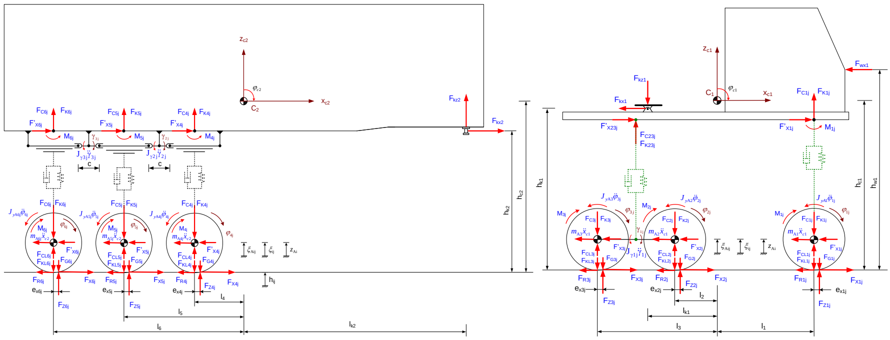
2 The three-dimensional (3D) dynamics model

The tractor semi-trailer has a very complex structure, belonging to amany objects system. Therefore, the authors used the method of structural separation of a multi-body system to build a three-dimensional (3D) dynamics model of the tractor semi-trailerin the coordinate system OXYZ. The 3D dynamics model of the tractor semi-trailer is divided into three models as follows:(i) The dynamics model of the tractor semi-trailer in the OXY plane; (ii) The dynamics model of the tractor semi-trailer in the OXZ plane; (iii) The dynamics model of the tractor semi-trailer in the OYZ plane [1, 2, 3, 4].



a. Semi-trailer **b.** Tractor

Fig. 1. The dynamics model of the tractor semi-trailer in the OXY plane



a. Semi-trailer **b.** Tractor

Fig. 2. The dynamics model of the tractor semi-trailer in the OXZ plane

The Newton-Euler equation was used to set up the system of dynamic equations of the tractor semi-trailer as follows [1, 2, 3, 4, 6, 7]:

$$(m_{c1}+\sum_{1}^{3}m_{Ai})\ddot{x}_{c1}=(F_{x1j}-F_{R1j})\cos\delta_{1j}-F_{y1j}\sin\delta_{1j}-(F_{R2j}+F_{R3j})+(F_{x2j}+F_{x3j})-F_{wx1}-F_{kx1} \tag{4}$$

$$(m_{c1}+\sum_{1}^{3}m_{Ai})\ddot{y}_{c1}=(F_{x1j}-F_{R1j})\sin\delta_{1j}+F_{y1j}\cos\delta_{1j}+F_{y2j}+F_{y3j}-F_{ky1} \quad (i=1\div 3) \tag{5}$$

$$\begin{aligned}J_{zc1}\ddot{\psi}_{c1}&=[(F_{x1j}-F_{R1j})\sin\delta_{1j}+F_{y1j}\cos\delta_{1j}]l_1+(F_{xi2}-F_{xi1}+F_{Ri1}-F_{Ri2})b_i-F_{yij}l_i\\&+(F_{x12}\cos\delta_{12}-F_{x11}\cos\delta_{11}+F_{y11}\sin\delta_{11}-F_{y12}\sin\delta_{12}+F_{R11}\cos\delta_{11}-F_{R12}\cos\delta_{12})b_1+F_{ky1}l_{k1}\end{aligned} \tag{6}$$

$$(m_{c2}+\sum_{4}^{6}m_{Ai})\ddot{x}_{c2}=(F_{xij}-F_{Rij})+F_{kx2} \quad (i=4\div 6) \tag{7}$$

$$(m_{c2}+\sum_{4}^{6}m_{Ai})\ddot{y}_{c2}=F_{ky2}+F_{yij} \quad (i=4\div 6) \tag{8}$$

$$J_{zc2}\ddot{\psi}_{c2}=(F_{xi2}-F_{xi1}+F_{Ri1}-F_{Ri2})b_i-F_{yij}l_i+F_{ky2}l_{k2} \quad (i=4\div 6) \tag{9}$$

$$m_{c1}\ddot{z}_{c1}=F_{Cij}+F_{Kij}-F_{kz1} \quad (i=1\div 3) \tag{10}$$

$$J_{yc1}\ddot{\varphi}_{c1}=(F_{Cij}+F_{Kij})l_i+F_{kz1}l_{k1}-F_{kx1}(h_{c1}-h_{k1})+M_{ij} \quad (i=1\div 3) \tag{11}$$

$$m_{c2}\ddot{z}_{c2}=F_{Cij}+F_{Kij}+F_{kz2} \quad (i=4\div 6) \tag{12}$$

$$J_{yc2}\ddot{\varphi}_{c2}=-(F_{Cij}+F_{Kij})l_i+F_{kx2}(h_{c2}-h_{k2})+F_{kz2}l_{k2}+M_{ij} \quad (i=4\div 6) \tag{13}$$

$$J_{xc1}\ddot{\beta}_{c1}=(F_{Ci2}+F_{Ki2}-F_{Ci1}-F_{Ki1})w_i+M_{kx1} \quad (i=1\div 3) \tag{14}$$

$$J_{xc2}\ddot{\beta}_{c2}=(F_{Ci2}+F_{Ki2}-F_{Ci1}-F_{Ki1})w_i-M_{kx2} \quad (i=1\div 3) \tag{15}$$

$$J_{Axi}\ddot{\beta}_{Ai}=(F_{Ci1}+F_{Ki1}-F_{Ci2}-F_{Ki2})w_i+(F_{CLi2}+F_{KLi2}-F_{CLi1}-F_{KLi1})b_i-F_{yij}(r_{ij}+\xi_{Aij}) \quad (i=1\div 6) \tag{16}$$

$$m_{Ai}(\ddot{z}_{Ai}+\dot{\beta}_{Ai}\dot{y}_{Ai})=F_{CLij}+F_{KLij}-F_{Cij}-F_{Kij} \quad (i=1\div 6) \tag{17}$$

$$m_{Ai}(\ddot{y}_{Ai} - \dot{\beta}_{Ai}\dot{z}_{Ai}) = F_i + F_{yij} \qquad (i = 1 \div 6) \qquad (18)$$

$$J_{Ayij}\ddot{\varphi}_{ij} = M_{Aij} - M_{Bij} - F_{xij}r_{dij} \qquad (i = 1 \div 6) \qquad (19)$$

3 Survey results and discussions

Matlab-simulink software was used to test the effects of braking torque on dynamic load of tractor semi-trailer. The tractor semi-trailer is moved on a straight road with the maximum longitudinal friction factor φ_{xmax} = 0.8 at speeds V_o= [60, 80]km/h. The tractor semi-trailer is braked with 6 braking torques M_B=[0.5, 0.6, 0.7, 0.8, 0.9, 1]M_{Bmax} (with $M_{Bmax}=F_G\varphi_{xmax}r_{dyn}$).

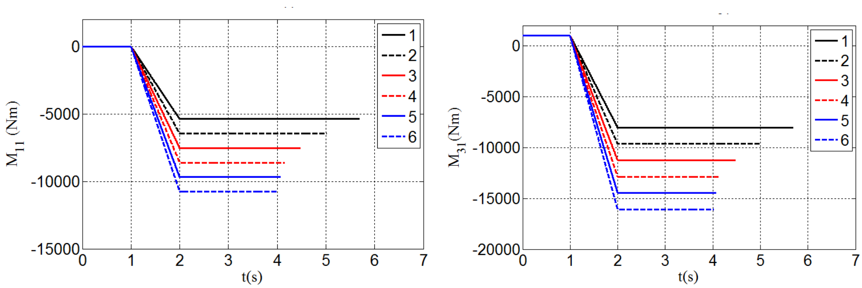
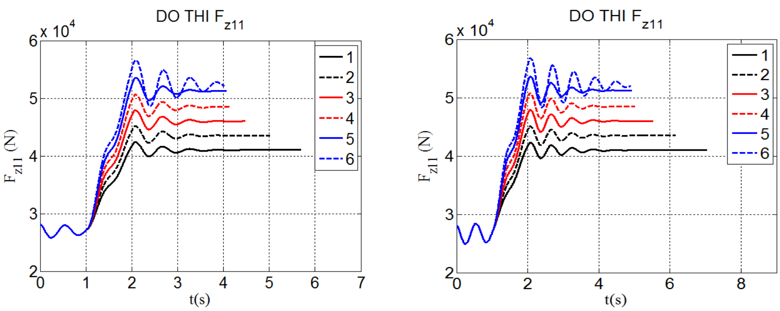


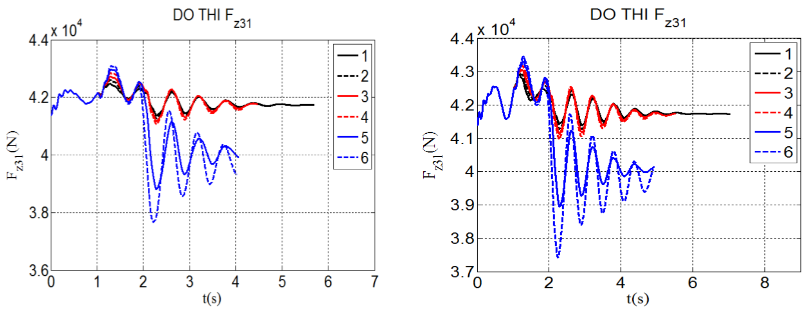
Fig. 3. The driving torque and braking torque

The input driving and braking torques of the survey model are shown in Figure 3, line 1 is M_B=0.5M_{Bmax}; line 2 is M_B=0.6M_{Bmax}; line 3 is M_B=0.7M_{Bmax}; line 4 is M_B=0.8M_{Bmax}; line 5 is M_B=0.9M_{Bmax}; line 6 is M_B=M_{Bmax}.



a. V_o= 60 km/h **b.** V_o= 80 km/h

Fig. 4. The wheel load on axle1



a. V_o= 60 km/h **b.** V_o= 80 km/h

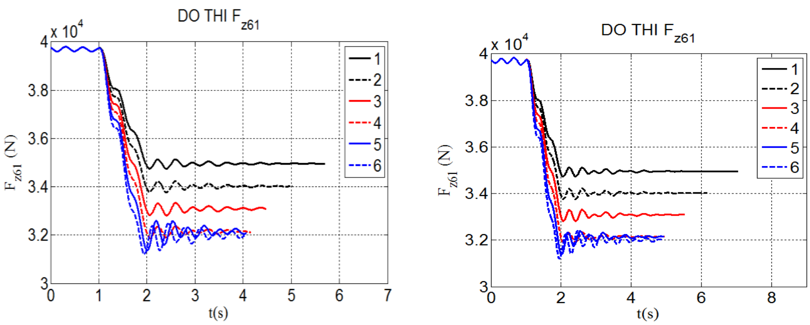
Fig. 5. The wheel load on axle 3

Figure (4, 5, 6) are the graphs of wheel load (F_{zij}) of the axle (1, 3, 6). From the graphs we see that, when the tractor semi-trailer is moved on a straight road with φ_{xmax}=0.8 at speeds V_o=[60, 80]km/h and then it is braked with 6 braking torques M_B=[0.5, 0.6, 0.7, 0.8, 0.9, 1]M_{Bmax}, the wheel force of axle 1 is increased, but the wheel force of axle 3 and the wheel force of axle 6 are decreased,

$$F_{Z11} = (2.8 \div 5.6)kN;\ F_{Z31} = (4.15 \div 3.6)kN;\ F_{Z61} = (3.98 \div 3.12)kN;$$

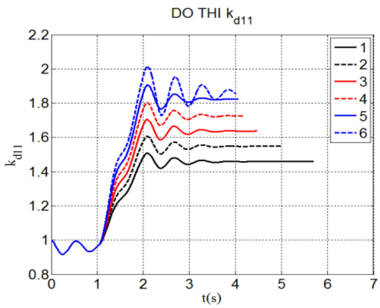
The graphs of dynamic load factor of the tractor semi-trailer (k_{dij}) are shown as figures (7, 8, 9). When the tractor semi-trailer is moved on a straight road with φ_{xmax}=0.8 at speeds V_o=[60, 80]km/h and then it is braked with 6 braking torques M_B=[0.5, 0.6, 0.7, 0.8, 0.9, 1]M_{Bmax}, the dynamic load factor of axle 1 is increased, but the dynamic load factor of axle 3 and the dynamic load factor of axle 6 are decreased,

$$k_{d11} = (1.0 \div 2.0);\ k_{d31} = (1.0 \div 0.91);\ k_{d61} = (1.0 \div 0.78).$$

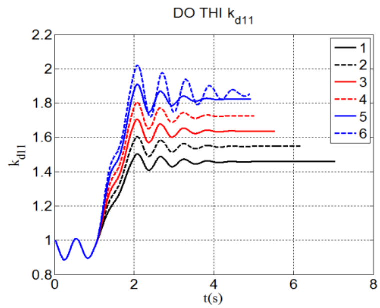


a. V_o= 60 km/h **b.** V_o= 80 km/h

Fig. 6. The wheel load on axle 6

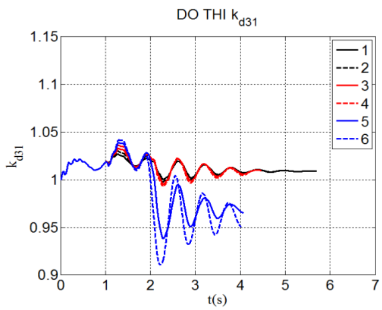


a. V_o= 60 km/h

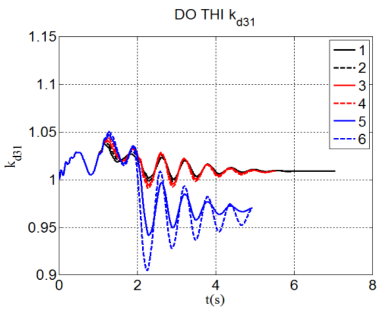


b. V_o= 80 km/h

Fig. 7. The dynamic load factor of the front axle

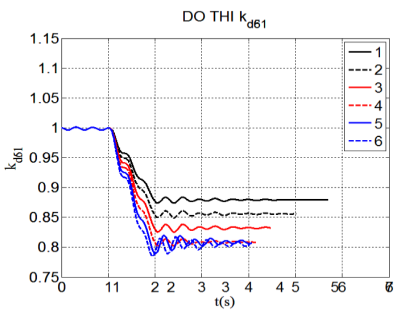


a. V_o= 60 km/h

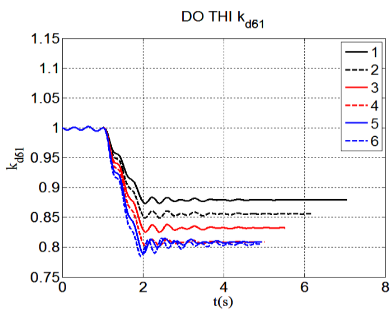


b. V_o= 80 km/h

Fig. 8. The dynamic load factor of the middle axle



a. V_o= 60 km/h



b. V_o= 80 km/h

Fig. 9. The dynamic load factor of the rear axle

4 Conclusion

When the tractor semi-trailer is moved on a straight road with φ_{xmax}=0.8 at speeds V_o=[60, 80]km/h and then it is braked with 6 braking torques M_B=[0.5, 0.6, 0.7, 0.8, 0.9, 1]M_{Bmax}. The wheel force of axle 1 is increased by 200%, but the wheel force of axle 3 is reduced about 13.3%, and the wheel force of axle 6 is reduced about 21.6%.

The dynamic load factor of axle 1 is increased by 200%, but the dynamic load factor of axle 3 is reduced about 9%, and the dynamic load factor of axle 6 is reduced about 22%.

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